NOAA Technical Memorandum NMFS-OF-5

MARINE ENVIRONMENTAL CONDITIONS OFF THE COASTS OF THE UNITED STATES JANUARY 1978 - MARCH 1979

Washington, D.C.
May 1980

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Marine Fisheries Service

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Elizabeth D. Haynes, Editor

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UNITED STATES
DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

National Marine Fisheries Service
Terry L. Leitzell, Assistant
Administrator for Fisheries

EXECUTIVE SUMMARY

Merton C. Ingham[1] and Douglas R. McLain[2]

During the winters of 1976-77 and 1977-78 a strong and persistent ridge of upper air circulation occurred over the west coast of North America from California to Alaska. This ridge brought southerly winds and mild temperatures to much of the coast. In Alaska the mild temperatures broke the period of abnormal cold of the early 1970's and allowed a remarkable recovery of salmon stocks.

During the 15-month period January 1978-March 1979, the upper air circulation over the northeastern Pacific Ocean shifted from the west coast ridge pattern of the previous two years and appeared to be returning to a more normal pattern. The west coast ridge reoccurred during the early part of the winter of 1978-79, but by the end of the winter it had shifted westward and weakened.

The pattern of anomaly of sea-surface temperature (SST) over the northeastern North Pacific shifted in association with the shifting pattern of atmospheric circulation. Whereas anomalies of SST had been generally negative in the central North Pacific and zero or positive near the west coast in 1977 and early 1978, in late 1978 and early 1979 the pattern shifted to one of positive anomalies in a large region between Hawaii and Alaska with negative anomalies all along the west coast. Whether this shift is truly indicative of a change from the pattern of the previous two years or not remains to be seen, because in summer 1979, after the end of the 15-month analysis period, the pattern of SST anomalies had reverted to the prevailing pattern of cold in the central North Pacific and warm along the eastern shore of the ocean.

The wind-driven surface ocean transport during January 1978-March 1979 was abnormal in several biologically important ways. During late 1977 and early 1978 strong northeastward transport occurred in the Gulf of Alaska and along the British Columbia coast. The resulting onshore transport resulted in an intrusion of southern, pelagic fauna into the area, and caused a large percentage of adult Fraser River sockeye salmon to return to the river through Queen Charlotte Sound rather than via the Strait of Juan de Fuca.

Off California, winter onshore transport was much stronger than normal during January-March 1978 and, to a lesser extent, again in December 1978-January 1979 and in March 1979. These strong onshore transports resulted in downwelling and thus extremely low computed indices of upwelling. The onshore transport held larvae of pelagic spawners such as anchovy and Pacific mackerel near shore and apparently resulted in better than normal recruitment. Associated with the onshore transports were stronger than normal northward flows of the California Counter Current or Davidson Current. Southern fauna such as trigger fish and billfish were caught in

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late summer 1978 off California; possibly their presence there was in response to increased northward currents.

In the Eastern Tropical Pacific, "anti-El Niño" conditions persisted throughout 1978 and early 1979, with strong upwelling and below normal sea-surface temperatures along the Equator. An index of the Southern Oscillation remained below normal, indicating generally weak trade winds and a low probability of El Niño conditions occurring in the near future.

in the Atlantic and Gulf coastal areas, 1978-79 was the third consecutive severely cold winter. These were the result of a deep and persistent atmospheric trough downstream from the west coast ridge. Three such cold winters in succession had never occurred before in the period of instrumental record in the United States. February air temperatures were lowest in 1978 south of Cape Hatteras on the Atlantic coast and in the northern Gulf of Mexico. In 1979 the greatest anomalies were found north of Norfolk, VA, on the Atlantic coast and in the northeastern Gulf of Mexico.

River runoff into Chesapeake Bay reached near or record high values in January and March in both 1978 and 1979, and also in May 1978. Flow into Long Island Sound reached record highs in January of both years, but remained near the long-term average values in other months. The Mississippi River flow reached relatively high, but not record, levels in March-May 1979, in contrast with the previous spring, when they were only about half as large.

Unusually large wind-driven transports occurred toward the south-southwest in December 1978 and toward the southwest in February 1979 in the southern New England area. These transports, the consequence of persistent west-northwest and northwest winds, occurred during the spawning periods of cod and haddock on Georges Bank. The drift of eggs and larvae in the plankton community in those months should have been strongly influenced by the anomalous transports. Off North Carolina there was a pronounced westward component in the wind-driven transport only in one month (February) of the 1979 winter spawning period of Atlantic menhaden. The component was less than half as large as that recorded in February 1978.

Sea-surface temperatures in the first three months of 1979 in the northwestern North Atlantic were up to 0.8°C (February) colder than the 1948-67 means for the area. The pattern was neither as intensive nor as extensive as that of January-March 1978. The pattern was similar in the Boothbay Harbor sea surface temperature data: anomalously cold in January-April 1979, but not as much as the comparable period in 1978. In the South Atlantic Bight, the anomaly pattern in the January-March periods of 1978 and 1979 were very similar, with February showing the largest negative anomalies, -1.24°C in 1978 and -1.36°C in 1979. Similar patterns were found in the Gulf of Mexico, once again showing the early months of 1978 to be colder than in 1979.

Apparently related to the variations in circulation and water masses was an absence of Gulf Stream warm core eddies near the continental shelf edge in the Georges Bank area during January-March 1978 and 1979. During these periods the Shelf Water/Slope Water front moved far seaward (up to 150 km) of its usual position near the edge of the Continental Shelf. The hiatus in eddy activity in 1978 was followed by an 8-month period (April-November) during which there was always an eddy or two adjacent to the bank, involving a total of six eddies. This period of eddy activity included the peak spawning months for several commercial species on the bank, but the amounts of eggs and larvae lost from the bank are unknown.

Bottom water on the shelf off southern New England (71°W) reached about the same minimum temperatures (<2°C) in February-March of both years, 1978 and 1979. In 1978 the unusually cold temperatures persisted in the mid-shelf cold cell into the summer period, remaining 1°-2°C lower than those measured during the previous four years. The offshore extension of the Shelf Water/Slope Water front was manifested in the bottom water also, reaching bottom depths of about 150 m in 1978 and 1979.

Off New Jersey the minimum bottom water temperatures in early 1978 were about 2°C warmer than 1977, but still were about 3°C colder than normal. By June, however, the cold cell bottom temperatures had warmed to about 4°C, about the same as in June 1977. In February 1979 bottom water temperatures were much like the minimum values of 1978, about 2°C in shallower water, but warmed 2°-4°C during the unusually mild March weather in the area. Seaward excursions of the Shelf Water/Slope Water front occurred in February-July and December 1978 and in March 1979. There was an absence of Gulf Stream warm core eddies off the middle Atlantic shelf during March-June 1978 and January-March 1979.

The Eastern Gulf Loop Current underwent a major northward extension (to about 30°N) into the Gulf of Mexico in spring and early summer of 1978. The timing of the extension fit the average pattern of variation, but the magnitude exceeded the average by about 3° latitude. The extension of Loop Current water onto the shelf is believed to have impacted on fisheries, yielding poorer harvests of brown shrimp, better catches of menhaden, and a red-tide bloom off the west Florida coast.

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INTRODUCTION

Elizabeth D. Haynes[1] and Douglas R. McLain[2]

This report is the fifth in an evolving annual series intended to provide fishermen and resource managers with a convenient synopsis of the marine environment.[3] The objective of the reports in this series is to describe in a timely manner the gross features of the marine environmental fluctuations in areas of interest to American fishermen, fishery biologists, and managers.

The fact that variations in the environment affect the distribution, abundance, and availability of fish has been recognized and studied for at least eighty years by the Council for the Exploration of the Sea and successor organizations. Such studies are a continuing effort of the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program of the National Marine Fisheries Service (NMFS). MARMAP is a major source of biological and other scientific information needed for management of the nation's fishery resources under P.L. 94-265, the Fishery Conservation and Management Act (FCMA) of 1976.

Duties and activities of MARMAP include the collection and analysis of the biological, chemical, and physical oceanographic data needed to provide basic information on the abundance, location, and condition of the commercial and recreational fishery stocks within the U.S. fishery conservation zone.

A major emphasis of MARMAP in recent years has been to develop mathematical models of marine populations, leading to improved methods for predicting fishery yields. Knowledge of environmental factors, particularly during critical phases of the development of a year class, and of the effects of variations of these factors, has proved to be of great importance in

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[1]Resource Assessment Division, National Marine Fisheries Service, NOAA, Washington, DC 20235.

[2]Pacific Environmental Group, National Marine Fisheries Service, NOAA, Monterey, CA 93940.

[3]Previous volumes in this series are:

Goulet, J. R., Jr. (compiler). 1976. The environment of the United States living marine resources - 1974. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., MARMAP Contrib. 104, 375 p.

Goulet, J. R., Jr., and E. D. Haynes (editors). 1978. Ocean variability: Effects on marine fishery resources - 1975. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 416, 350 p.

Goulet, J. R., Jr., and E. D. Haynes (editors). 1979. Ocean variability in the U.S. fishery conservation zone, 1976. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 427, 362 p.

Pedrick, R. A., M. C. Ingham, D. R. McLain, J. Namias, and others. 1979. Marine environmental conditions off the coasts of the United States, January 1977-March 1978. Mar. Fish. Rev. 41(5-6): 20-69.

All are available on request from NOAA, NMFS, F/SR2, 3300 Whitehaven Street, N.W., Washington, DC 20235.

these models.

Historically, each species has been managed as if it existed alone in a stable or "average" environment. Modern computers have made it possible to express interrelationships among species mathematically and thus to develop "ecosystem" models. The various effects of the environment and its variations in time and space on the different species of the ecosystem can also be included in the model. The changing of controllable factors, such as harvest rates and total annual catches, can be tested before the fishing season by "running" the model on the computer under various assumptions to determine which fishing strategies appear to be most productive and least damaging to the stocks.

Scientists within NMFS have considerable expertise in fisheries analysis and population dynamics. The Atlantic and Pacific Environmental Groups within NMFS were created under the MARMAP program to apply environmental data to the solution of fisheries problems. Notable progress has been made in many cases, with considerable success in several instances, by using the modeling approach and including environmental parameters. Annual environmental reports are issued by the Environmental Groups in cooperation with the Fishery Research Centers and others.

This volume presents an overview of the climatological variations of the year 1978 and first quarter of 1979, and mentions possible environmental effects on species of interest to commercial fisheries. It reflects the availability of recent oceanographic information as well as the authors' judgement regarding those parameters which affect marine populations.

Information on fluctuations of ocean circulation would be particularly desirable in these reports, but routine measurements of ocean currents are sparse and not directly intercomparable. It is necessary to use indirect measures of ocean circulation such as calculations of Ekman transport and upwelling indices, and measurements of sea level and sea-surface temperatures (SST) to infer circulation changes. Also, it is desirable to look first at the atmospheric large-scale driving forces of the ocean as an aid in understanding the smaller-scale regional oceanographic and biological effects. Therefore the report first presents descriptions of the large scale fluctuations in atmospheric circulation, surface (Ekman) transport, upwelling, sea level, and SST to define the major changes in oceanic conditions during the period and relative to prior years. Discussions of regional fluctuations of SST, salinity, river discharge, and biological factors are then presented for areas along the Pacific coast of North America from the eastern Bering Sea to the eastern tropical Pacific and along the Atlantic Coast from the Gulf of Maine to the Gulf of Mexico.

The data presented in this report are primarily physical, since such data are available more widely and more rapidly than biological observations. It is hoped that these descriptions will be of use to biologists in identifying unusual observations of marine organisms and relating them to environmental events. The authors encourage readers to note and report unusual biological occurrences. Such reports are published in periodicals such as the University of Rhode Island's quarterly newsletter, Coastal Oceanography and Climatology News, which includes unusual observations from both the Pacific and Atlantic coasts. A form for reporting unusual biological observations in Alaska has been developed by Dr. R. R. Straty of the NMFS laboratory at Auke Bay, AK 99821, and Alaskan readers are encouraged to submit reports to him. Many other sources of data on oceanographic fluctuations are available. Fishing Information is published monthly by the Southwest Fisheries Center, NMFS, La Jolla, CA 92038. It contains maps

of monthly mean surface pressure, winds, and SST, and a vertical section of subsurface temperature in the Pacific. The gulfstream, published monthly by the Oceanographic Services Branch, National Weather Service, Silver Spring, MD 20910, focuses on Gulf Stream eddy activity and SST's and their anomalies off the U.S. east coast. The Monthly Weather Review and Weatherwise are published under the sponsorship of the American Meteorological Society, Boston, MA 02108, and provide monthly descriptions of weather conditions. National Fisherman, Camden, ME 04843, is a monthly newspaper with many articles of interest to the oceanographic community as well as to the commercial fisherman, including effects of weather. The reader is referred to these sources for additional details on environmental fluctuations and for timely updates of changing conditions.

In view of the availability of information from the other established sources listed above, this series will be discontinued with this volume. The Atlantic and Pacific Environmental Groups will continue to issue their annual reports and will respond directly to specific requests from NMFS users for oceanographic data and other information.

MARINE ENVIRONMENTAL CONDITIONS IN THE EASTERN NORTH PACIFIC OCEAN
January 1978 - March 1979

Douglas R. McLain[1] and W. James Ingraham, Jr.[2]

LARGE-SCALE MARINE CLIMATIC CONDITIONS

Atmospheric Circulation

Wagner (1979) described the atmospheric circulation and weather over North America during 1978. The winter 1977-78 and the first part of the winter 1978-79 continued a pattern of atmospheric circulation begun in 1976-77 in which a strong ridge of atmospheric pressure formed along the west coast with a trough downstream over the central or eastern United States (Fig. 1). This circulation continued the pattern of winter 1976-77, with mild temperatures and abundant precipitation in Alaska areas with cold, snowy weather to the east. During winter 1977-78 temperatures along the California coast were near or above normal and precipitation was abundant as the ridge allowed storms to move in from the southwest. During December 1978 and January 1979 the ridge formed again but was shifted to the west several hundred kilometers off the coast and extended northwards over Alaska. This allowed some northerly flow over the west coast, bringing below normal temperatures, especially over the southern part of California. By February 1979 the ridge shifted farther west and became an "omega type" blocking ridge over the Bering Strait (Dickson 1979). This led to the formation of a trough near the west coast which brought above normal precipitation to much of the coast.

Surface Pressure

Maps of the distribution of surface barometric pressure are available routinely from many agencies (see, for example, those published in Fishing Information); for brevity they are not reproduced here. These maps show the Aleutian low pressure system centered near the Aleutian Islands in winter with resultant westerly winds over much of the North Pacific. In spring and summer the low fills and weakens and the North Pacific high-pressure system expands from off California so that by August the high dominates the circulation of the northeastern Pacific. In fall the high-pressure cell contracts and the Aleutian low deepens and resumes its normal winter position over the Aleutians.

This annual pattern of pressure distribution occurred in 1978 and early 1979 with several variations. In early 1978 strong westerly winds occurred over much of the northeastern Pacific and apparently caused strengthened flow of the California Current. In September 1978 an isolated low-pressure system occurred in the Gulf of Alaska.

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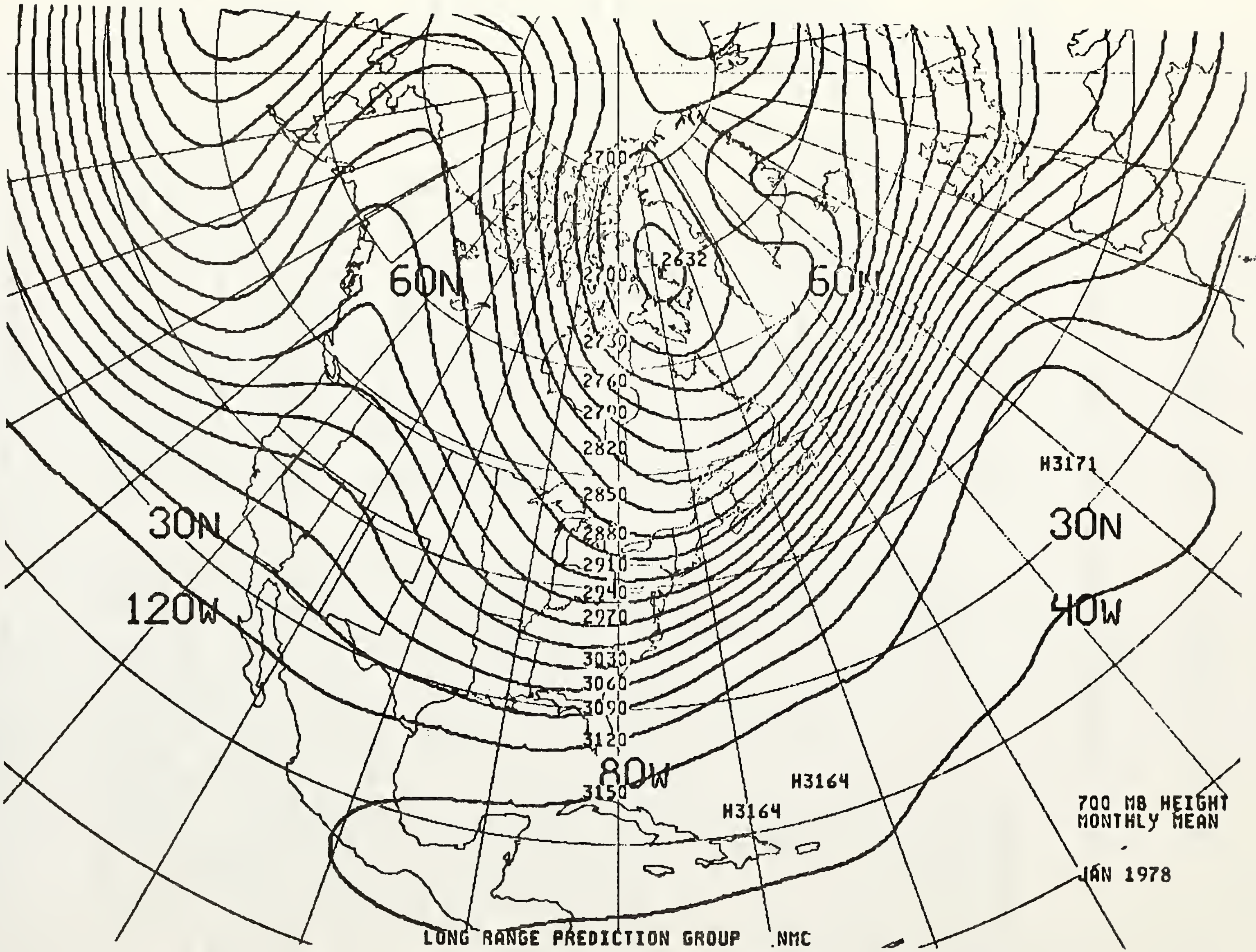
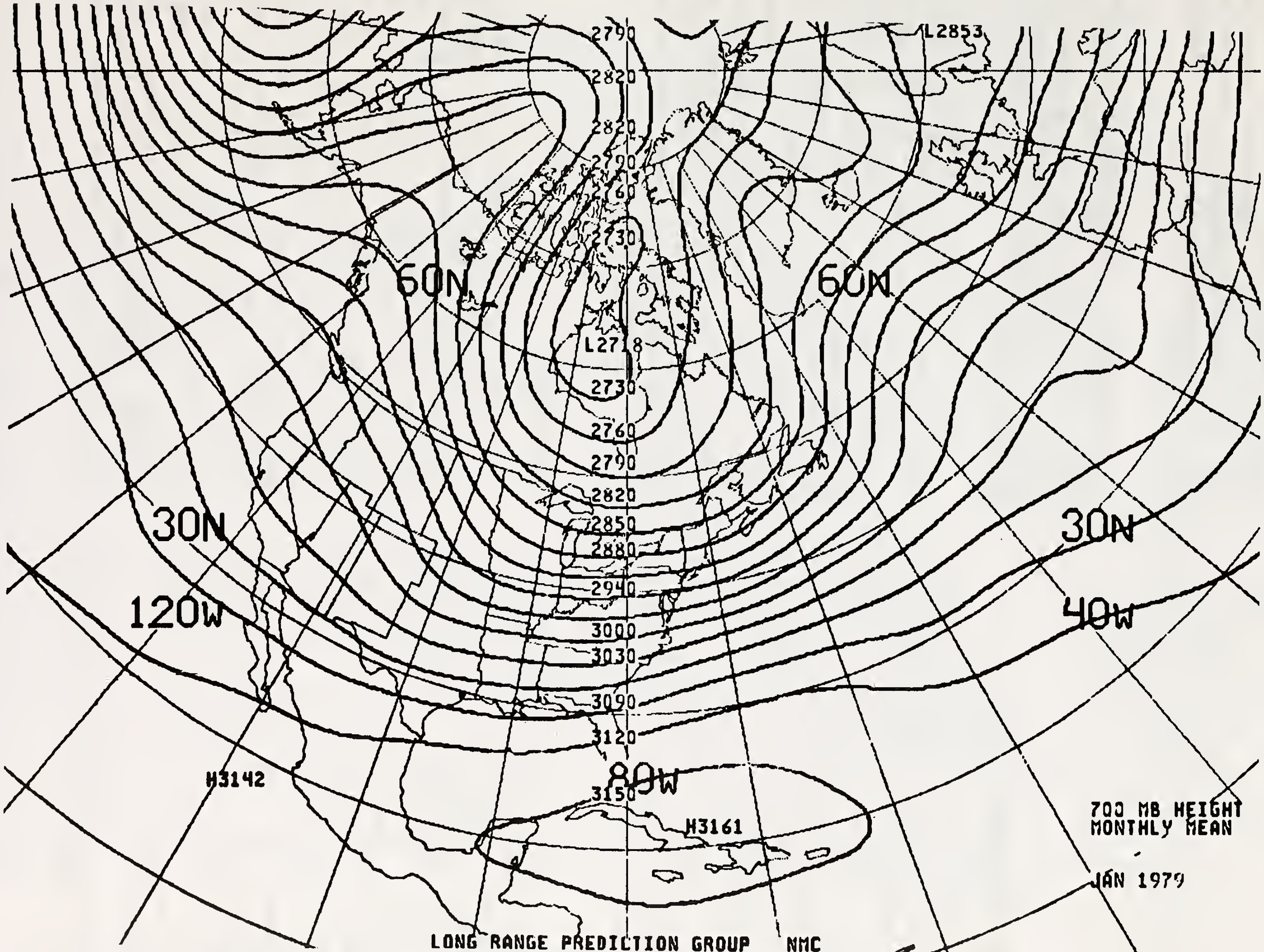


Figure 1.--Height of the 700 mb pressure surface (meters) in January 1978 (upper) and January 1979 (lower). From 30^{o}-60^{o}N the upper level winds flow generally west to east (midlatitude westerlies) parallel to the contour lines, carrying with them to some extent the air mass conditions of temperature and humidity of upstream areas. The closer the spacing of the contour lines, the steeper the height gradient of the pressure surface, and the



faster the wind speeds; thus the farther downstream the upstream air mass characteristics may be carried. In general, under a pressure surface ridge or area of divergence of the contour lines, weather is fair, warm, and dry; under a trough or area of convergence of the contour lines, weather is likely to be cloudy, cold, wet, and stormy. Charts supplied by the Long Range Prediction Group, NWS, Washington, DC 20233.

In January 1979 an intense Aleutian low was present over the central Aleutians, while the North Pacific high was shifted to the west of its normal position, thus causing strong southwesterly winds in the region between it and the low. In February the low split into an eastern and western portion with the eastern portion centered over the Gulf of Alaska near southeastern Alaska.

Wind-Driven Transport

The oceanic surface layer transport due to surface wind stress is estimated monthly by calculations of wind-driven (Ekman) transport using monthly mean fields of surface barometric pressure. These data are summarized as vectors of transport by month at selected points in the northeast Pacific.[3] Figure 2 shows monthly vectors of computed transport for the 15 months January 1978-March 1979, while Figure 3 shows the long-term monthly mean vectors (January-March repeated).

During late 1977 and early 1978 there was stronger than normal northeastward Ekman transport in the Gulf of Alaska (57°N, 140°W) and northeastward rather than the normal southeastward flow at 50°N, 133°W. This northeastward transport moved water towards the shore, which resulted in downwelling along the coast of southeastern Alaska and British Columbia and caused a strengthening of the northerly flow along the coast. Biological implications included a massive intrusion of salps into the area. Strong northward transport occurred at 57°N, 170°W in the Bering Sea.

At the two locations, 39°N, 149°W and 27°N, 140°W, there was unusually strong southeastward transport in January-February 1978, and at 27°N, 140°W, the transport was also southeastward rather than the normal northward flow. These transports resulted from the strong atmospheric circulation over the eastern North Pacific during winter 1977-78.

Transports during spring and summer 1978 were near normal values with the exception of strong offshore transport off California (39°N, 128°W) during May-July.

During winter 1978-79 several large anomalous transports occurred. In the Gulf of Alaska (57°N, 140°W) transport was southeastward in early winter rather than in the usual northeastward direction. Very strong northward transport occurred at 57°N, 140°W in February 1979. South of Kodiak (50°N, 153°W) strong southeastward transport occurred in October and December. Off California (39°N, 128°W) there was strong southeastward transport in February 1979.

Upwelling

Bakun (1973) computed an index of coastal upwelling using the component of Ekman transport normal to the coastline at 15 locations along the west coast from the Gulf of Alaska to Baja California. Historical values of upwelling index are presented in Figure 4 for the period of record, 1946 to the present, as anomalies from the long-term mean of the reference period 1948-67. This period is used for various other data sets in this report and also is used as a reference period by Fishing Information. Positive values of the index represent upwelling, and negative values represent downwelling.

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[3] A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940. Values are computed on a grid of 3 degrees of latitude and longitude from data of Fleet Numerical Oceanobraphy Center, Monterey, CA 93940.

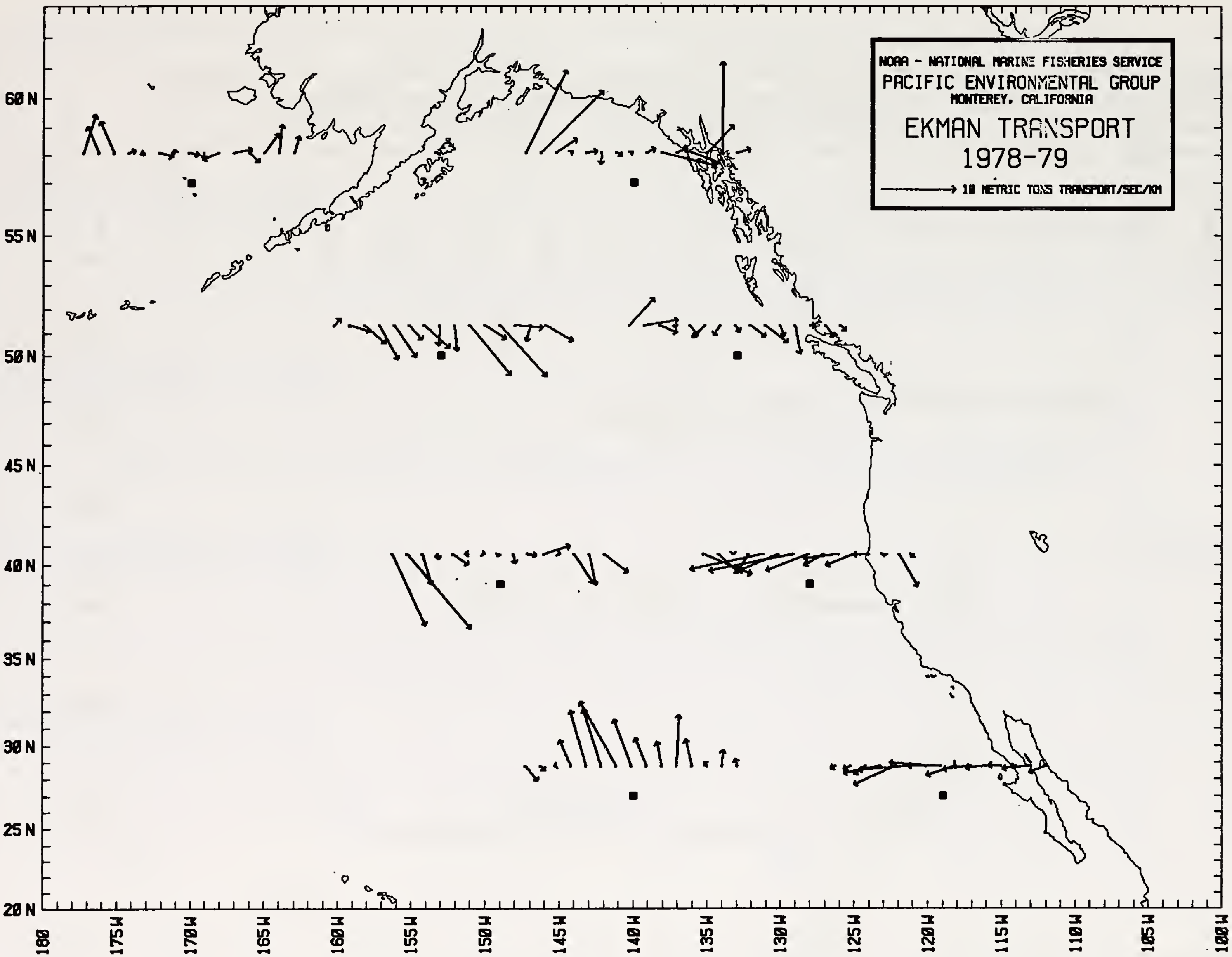

Figure 2.--Vectors of monthly mean Ekman transport for 15 months during January 1978-March 1979 for selected points in the eastern North Pacific, computed over a 3-degree area of latitude and longitude. Points are shown as black squares. Data from A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940.

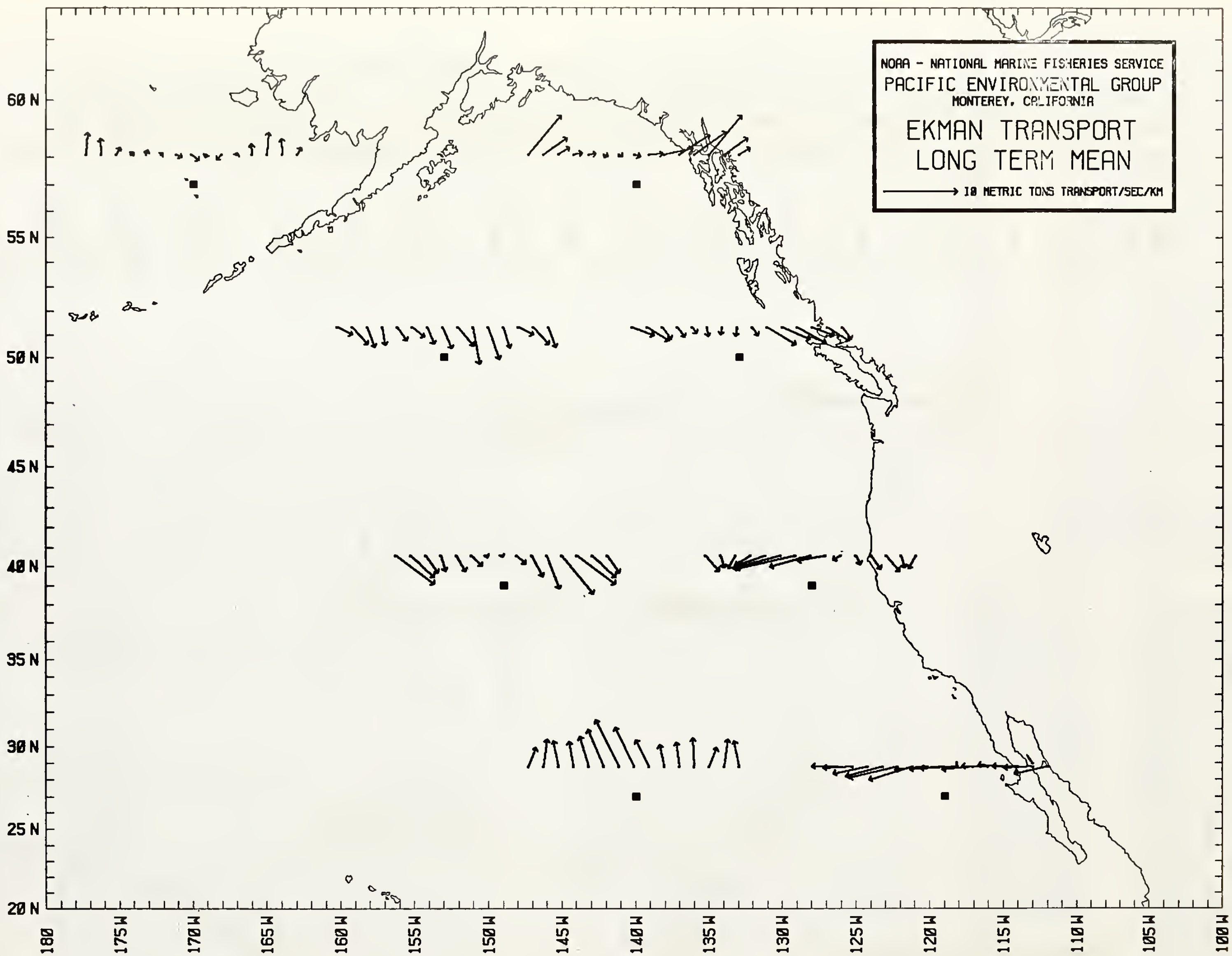

Figure 3.--Long-term mean monthly Ekman transport for 15 months (January-March repeated) for the reference period 1948-67 for selected points in the eastern North Pacific, computed over a 3-degree area of latitude and longitude. Points are shown as black squares. Data from A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940.

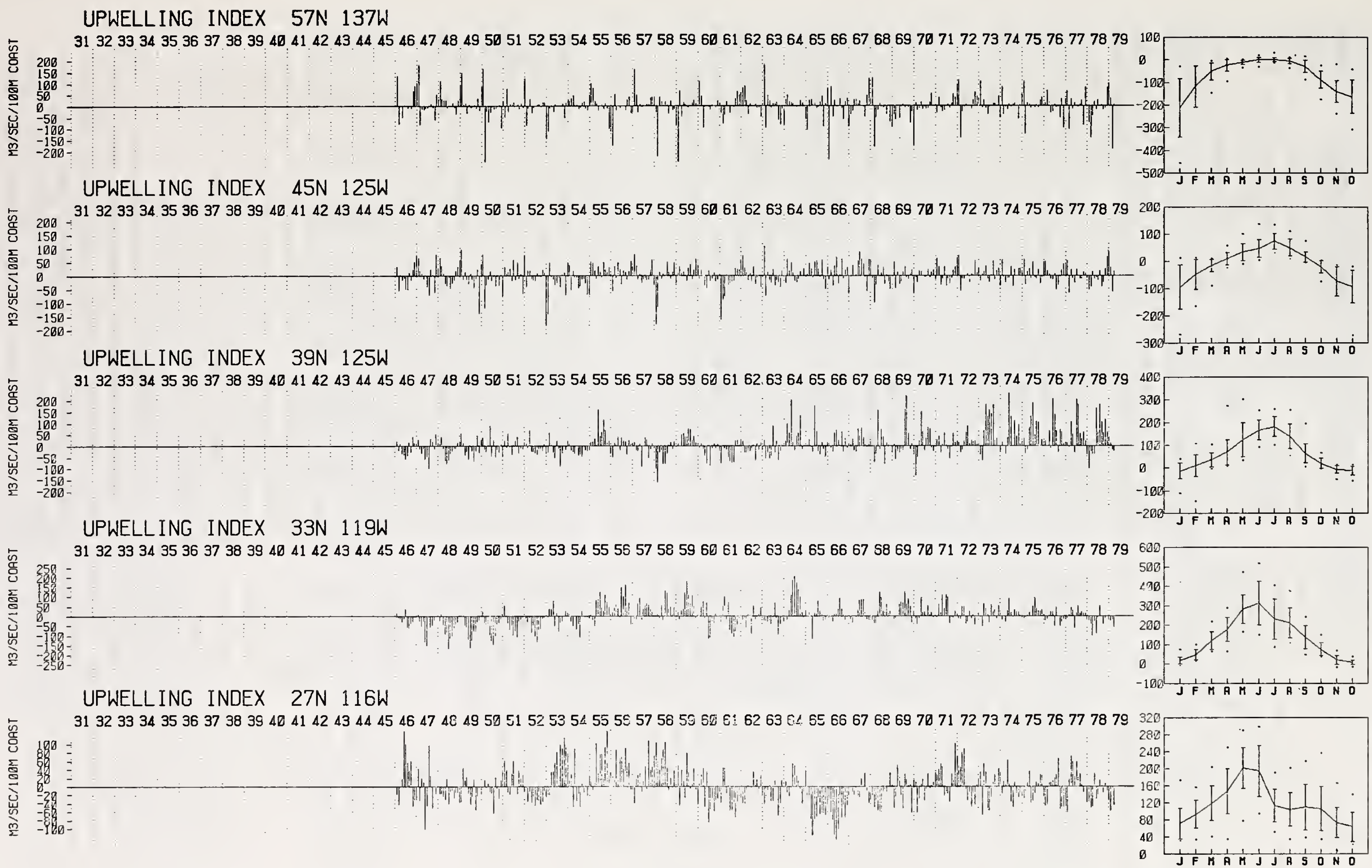

Figure 4.--Time series for 1931-79 of anomaly of upwelling index in cubic meters of water per second per 100 meters length of coastline from the long-term mean reference period 1948-67. Data from A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940. Small boxes on the right-hand side of this and other time series plots show the annual cycle with the range and standard deviation of interannual variations during the reference period.

The area of maximum upwelling along the west coast is centered near $39^{\circ}N$, $125^{\circ}W$ (Bakun et al. 1974), although numeric values of the upwelling index are higher off southern California due to an effect of coastal mountains (Bakun 1973). For the sixth year in a row, upwelling at $39^{\circ}N$, $125^{\circ}W$ was generally above normal during 1978. In early 1979 upwelling indices at $39^{\circ}N$, $125^{\circ}W$ were near normal.

Farther south at $33^{\circ}N$, $119^{\circ}W$, upwelling indices have been near normal in recent years, whereas at $27^{\circ}N$, $116^{\circ}W$, values have been generally below normal. North of $39^{\circ}N$ upwelling is less important and downwelling in winter becomes dominant. At $45^{\circ}N$, $125^{\circ}W$ and $57^{\circ}N$, $137^{\circ}W$ upwelling indices in recent years have been variable, but near normal values.

Details of the variations of upwelling indices in 1978 and early 1979 at all 15 locations along the coast are presented in Figure 5. The data are presented as percentiles of occurrence of values of upwelling index at that location over the period of record (1946 to date). By taking percentiles of the values, the data are normalized and can be intercompared. Low percentiles indicate increased downwelling or decreased upwelling while high percentiles indicate increased upwelling or decreased downwelling.

Although upwelling indices were generally high during 1978, at $39^{\circ}N$, $125^{\circ}W$ during January-March they were below normal and were unusually low from 30° to $36^{\circ}N$. Extreme low index values occurred at $36^{\circ}N$, $122^{\circ}W$ in January and from $30^{\circ}N$ to $36^{\circ}N$ in March. This was a case of predominant onshore transport and downwelling during a period of light or southerly winds associated with a persistent high-pressure system and drought conditions then occurring over California. The onshore transport apparently concentrated fish larvae near shore, as will be mentioned later.

During May-July upwelling conditions returned to more normal ranges. Upwelling was stronger than normal north of $51^{\circ}N$ in June and north of $39^{\circ}N$ in July. Weak upwelling occurred from 42°-$54^{\circ}N$ in August and September. Upwelling indices then returned to abnormally high values in October-December north of $36^{\circ}N$. Intense upwelling conditions in Gulf of Alaska waters may have resulted in anomalous offshore transports of fish larvae. During December 1978 and early 1979 onshore transport again occurred off central and southern California. This was a similar occurrence to that in early 1978, but was much less extreme.

Extremely high upwelling indices were calculated at $21^{\circ}N$, $107^{\circ}W$ throughout the period. Similar high values occurred during 1977. Because the high values occurred only at the one location, $21^{\circ}N$, $107^{\circ}W$, and not to the north, the data appear questionable; the cause is not known, but it may be due to a change in analysis procedures of the surface pressure observations.

Sea Level

Long historical records of tide height are available for many tide gage stations along the coast. Tide height is primarily affected by astronomical factors, but also by oceanographic and meteorological factors including variations in speed of alongshore currents (Reid and Mantyla 1976). Most of the tidal effects are relatively short-term and can be averaged out by making monthly means of the hourly tide height observations. Meteorological and long-term (nodal) tide effects can be compensated for, and thus tide height or sea-level data can be used to infer changes in ocean circulation.

Bretschneider and McLain (1979) presented monthly mean sea-level data for a series of stations along the west coast of North and South America from the Aleutian Islands to Chile. They showed that anomalies of monthly mean

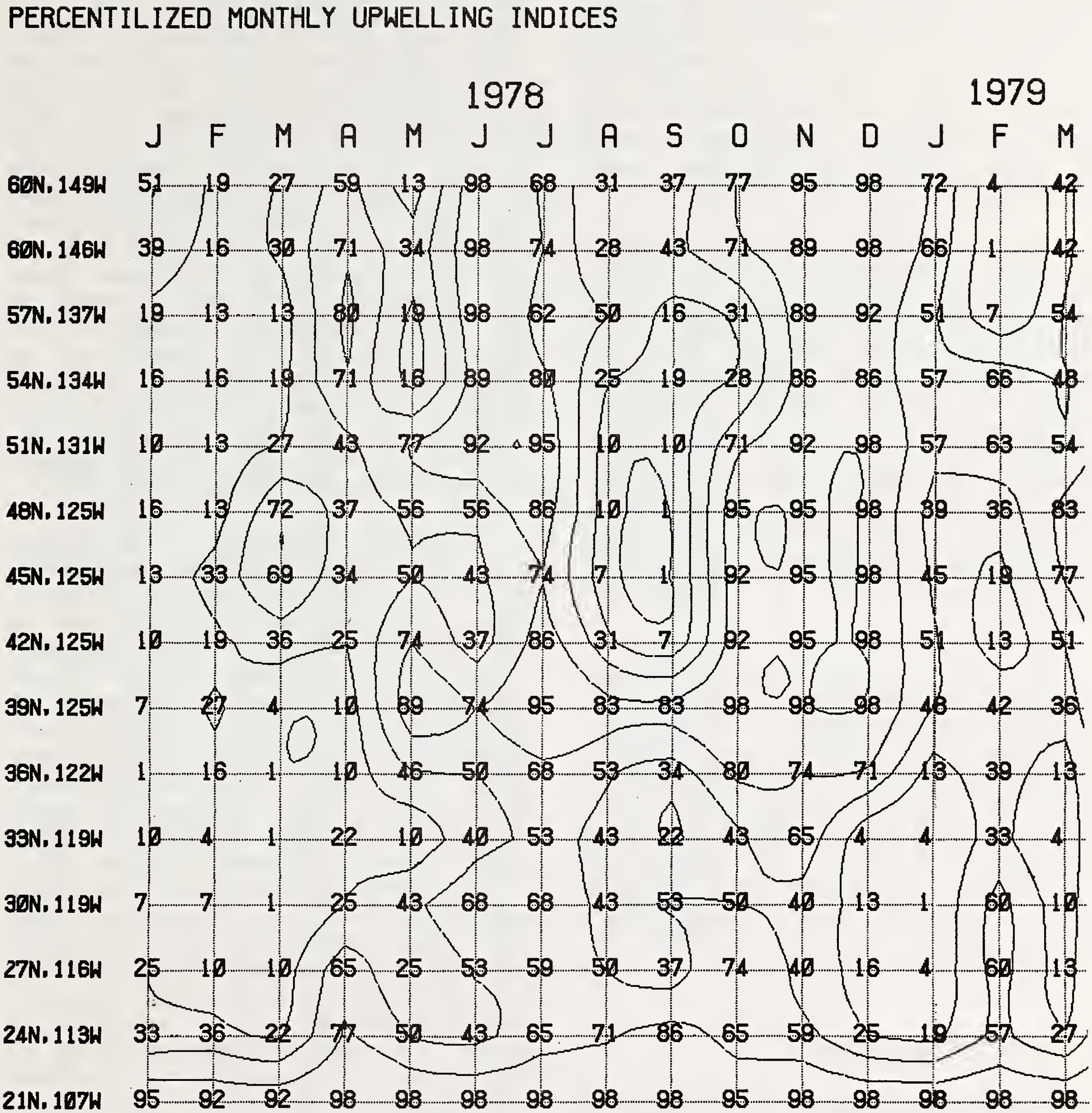

Figure 5.--Monthly upwelling index values for January 1978-March 1979, in percentiles of the frequency distributions made up of the 34 values for each month and location in the 34-year (1946-79) time series. Locations in the Gulf of Alaska are toward the top of the figure; those off Baja California are toward the bottom. The contour interval is 25 percentiles. Values above the 50th percentile indicate stronger than normal upwelling, while those below the 50th percentile indicate weaker than normal upwelling.

sea level from a long-term mean are remarkedly coherent in time and space. In particular, they showed that periods of high sea level can be traced southward along the coast from Alaska to Chile and are associated with above normal sea-surface temperatures along the coast and with El Niño occurrences in the Eastern tropical Pacific.

Some sea-level data are available for west coast tide stations during 1978.[4] Anomalies of monthly means from the long-term mean are presented in Figure 6 for five stations with the most complete data records. Above normal sea levels occurred along the California coast in 1940-41, 1957-59, and 1972-73, as discussed by Bretschneider and McLain, and were associated with major El Niño occurrences. The periods of above normal sea level can be traced northwards to Alaska but are obscured there by effects of storms.

In 1976 there was a minor El Niño and high sea levels were observed at California stations in late 1976. High sea levels also occurred in the winters of 1977-78 and 1978-79, probably as a result of onshore wind-driven transport. Data from the northern stations, particularly Yakutat, AK, are incomplete, but show low sea levels in late 1978. Possibly higher than normal levels existed in early 1978 in response to onshore transport.

Sea-Surface Temperature

Spatial Variations - Analyzed maps of sea-surface temperatures (SST) and their anomalies from a long-term monthly mean are published monthly in Fishing Information and are not reproduced here. (also see Appendix.) These maps showed that a large pool of cooler than normal water formed in the northeastern Pacific during late 1977 and persisted into 1978. In early 1978 the pool was located at 35°-40°N, 140°W to 180°, and was bordered on the east and north by a coastal strip of warmer than normal water. By May the pool had expanded northward to the Alaska coast and by August it reached eastward to the California coast. Breakup of the anomaly pattern then began, and by December a warmer than normal pool occupied the central portion of the northeastern Pacific surrounded by cooler than normal water. This general pattern persisted through March 1979.

Temporal Variations - Johnson et al. (1976, 1978) presented time series plots of SST for selected 5-degree squares of latitude and longitude in the North Pacific. These squares, called Index Stations, were chosen because of a relatively large number of available ship weather observations. Johnson et al. chose 10 such areas along the coast of the northeast Pacific from the central Aleutian Islands to Equador (Table 1). Time series of SST for these areas for 1931-79 are shown in Figures 7 and 8 as anomalies from a long-term mean (1948-67).[5] Because of the scarcity of SST data from the Bering Sea, air temperature data[6] from St. Paul, Pribilof Islands, are also also included in Figure 7. Details of fluctuations of SST along the coast are discussed later.

SST's along the coast of North and

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[4]Provided by J. R. Hubbard, Tides and Water Levels Division, National Ocean Survey, NOAA, Rockville, MD 20852. Recent data are provisional and are based on preliminary datums. The time series of monthly mean sea levels have been detrended to eliminate long-term trends, and corrected for the inverse barometer effect of atmospheric pressure. The 19-year period 1949-67 was used as a long-term mean for sea level to correct for nodal tide effects (Bretschneider and McLain 1979).

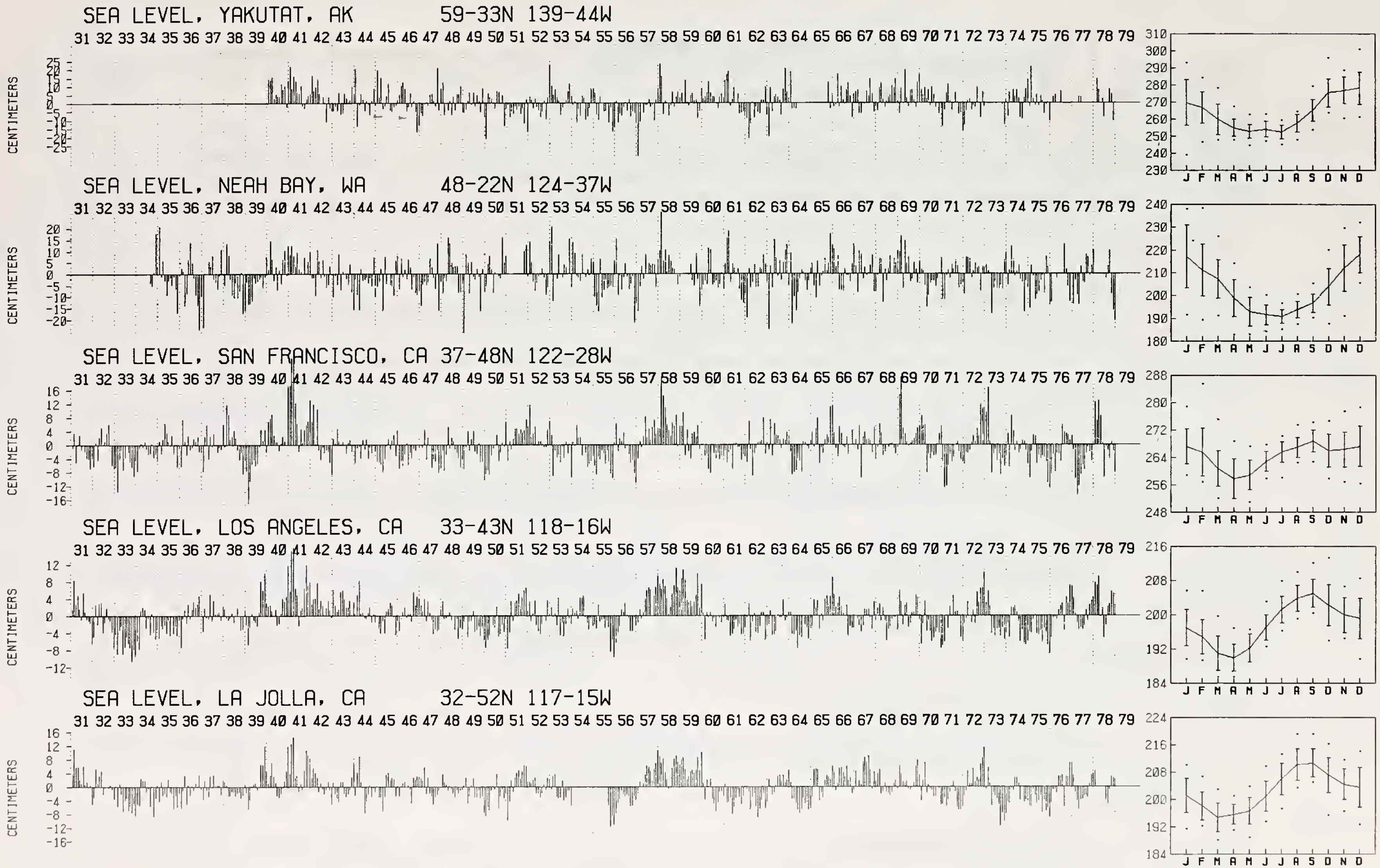

Figure 6.--Time series for 1931-79 of anomaly of sea level in centimeters from the long-term mean reference period 1949-67 at tide gages from Alaska to California. Data from J. R. Hubbard, National Ocean Survey, NOAA, Rockville, MD 20852.

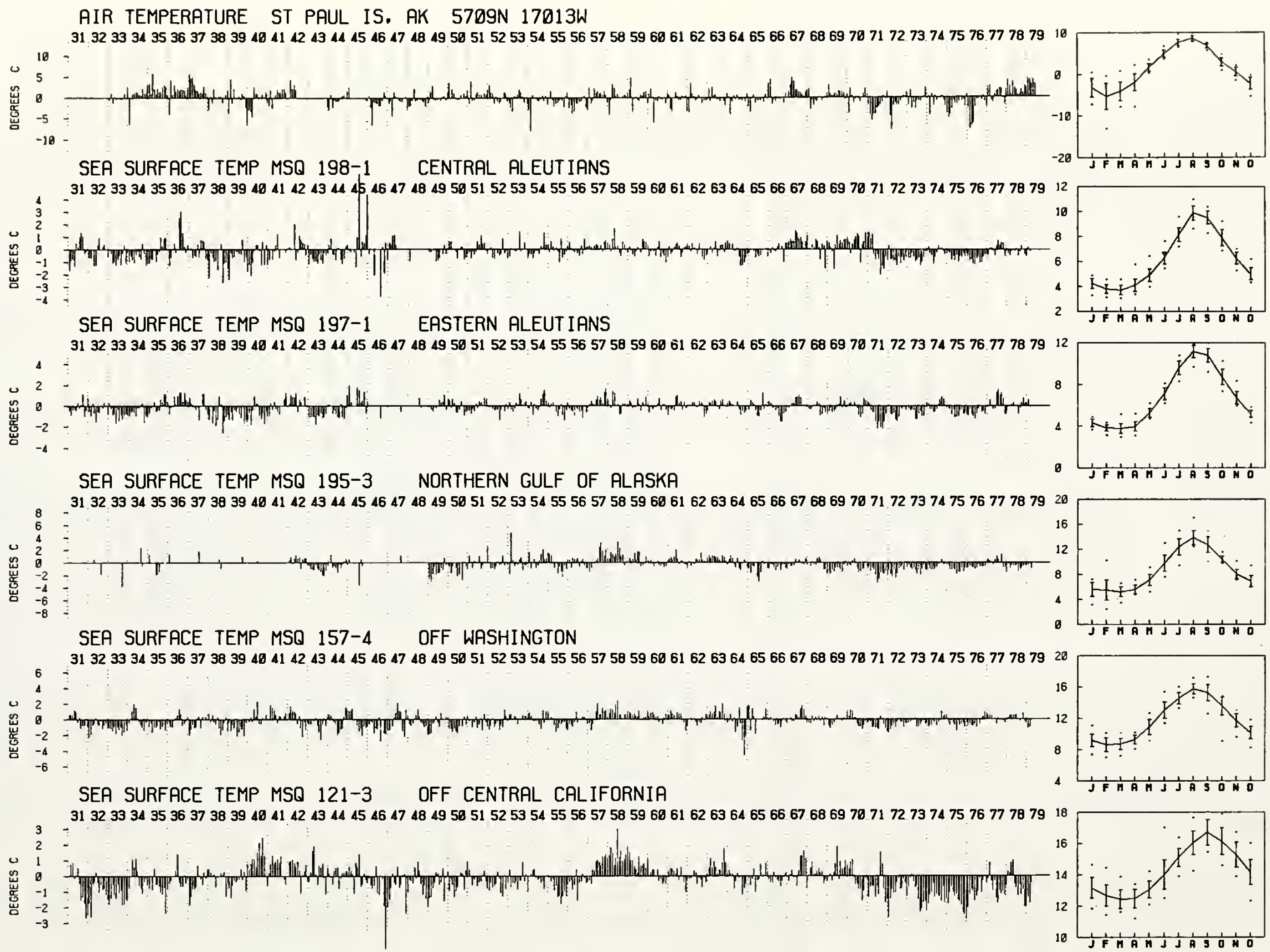

Figure 7.--Time series for 1931-79 of anomaly of air temperature in degrees Celsius at St. Paul Island, AK, and sea-surface temperature in degrees Celsius from the long-term mean reference period 1948-67 at five 5-degree squares of latitude and longitude along the coast from the Aleutian Islands to California. Air temperature data for St. Paul Island and sea-surface temperature data for 1931-71 from the National Climatic Center, EDIS, Asheville, NC 28801; SST data for 1972-79 from Fleet Numerical Oceanography Center, Monterey, CA 93940.

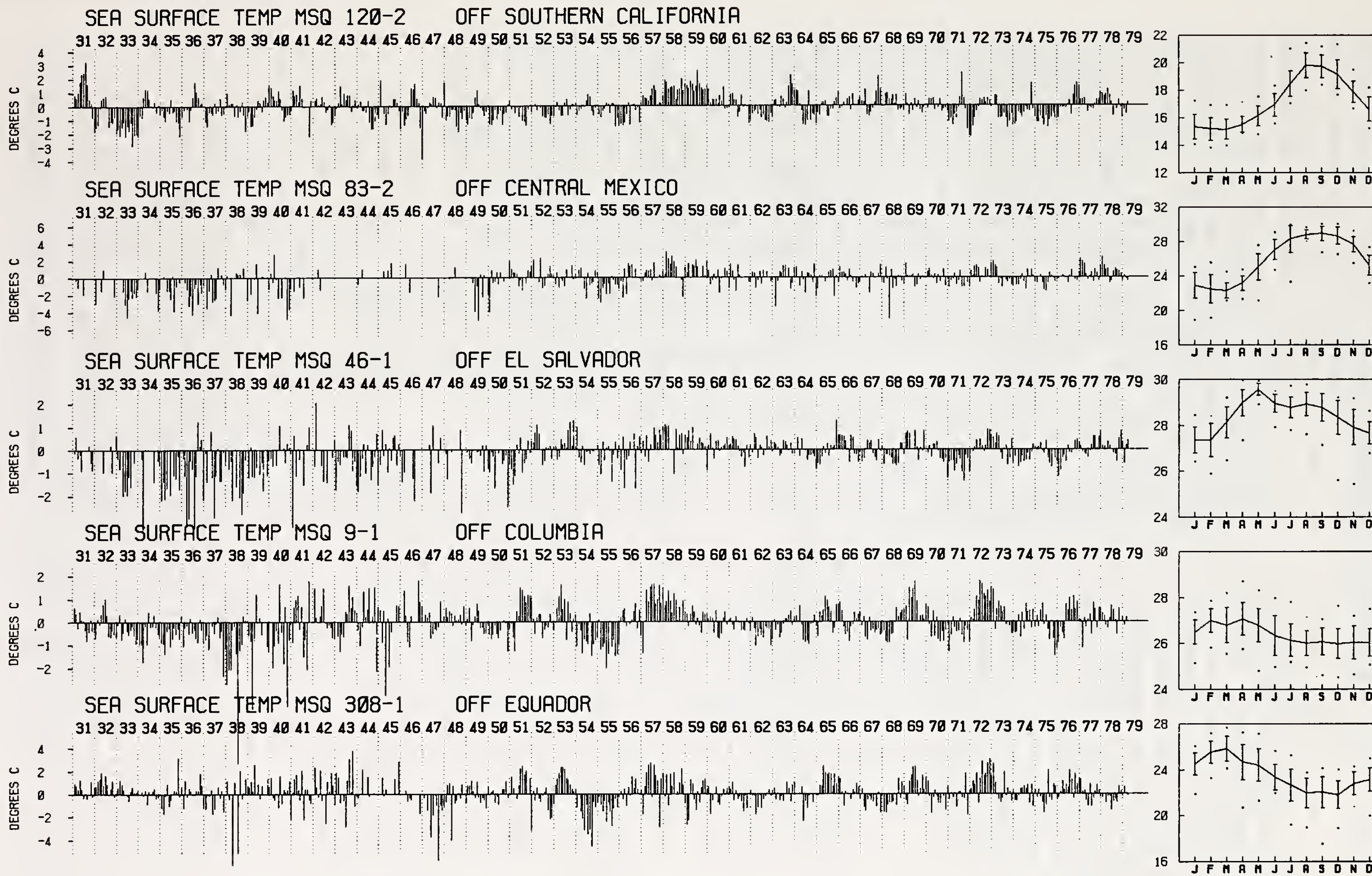

Figure 8.--Time series for 1931-79 of sea-surface temperature in degrees Celsius from the long-term mean reference period 1948-67 at five 5-degree squares of latitude and longitude along the coast from California to Ecuador. Data for 1931-71 from the National Climatic Center, EDIS, Asheville, NC 28801; data for 1972-79 from Fleet Numerical Oceanography Center, Monterey, CA 93940.

Central America have shown similar variations with time along extensive stretches of coast. Temperatures in the early 1940's and during 1958-59 were above normal over most of the coast, while temperatures in the early 1930's, late 1940's, 1955-56, 1970-71, and 1974-75 were below normal in most areas. The years 1972-73 and 1976 had above normal temperatures along the Central American coast in association with recent El Niño occurrences, but had near or below normal temperatures in the northern areas.

A prolonged period of below normal SST in the Bering Sea and Gulf of Alaska during 1971-76 was broken in 1977, and temperatures along the coast have been near or above normal since then. In early 1977 air temperature at St. Paul Island and SST from the Aleutians (square 198-1) to Washington (square 157-4) became near or warmer than normal. Off California, SST's remained generally below normal except for near normal temperatures off central California (121-3) and above normal off southern California (120-3) in the winter of 1976-77 and in early 1978. This pattern continued to the south off Central America with above normal temperatures in winter 1976-77 and early 1978. Off Ecuador (square 308-1), SST's have been near normal since 1977.

Table 1.--Locations of Index Stations for time series of sea-surface temperature data along the coast of the northeast Pacific Ocean.

Location	Latitude	Longitude	Marsden 5° square
Central Aleutians	50°-55°N	170°-175°W	198-1
Unimak Pass	50°-55°N	160°-165°W	197-1
Gulf of Alaska	55°-60°N	140°-145°W	195-3
Off Washington	45°-50°N	125°-130°W	157-4
Off Central California	35°-40°N	120°-125°W	121-3
Off Southern California	30°-35°N	115°-120°W	120-2
Off Central Mexico	20°-25°N	105°-110°W	83-2
Off El Salvador	10°-15°N	90°- 95°W	46-1
Off Colombia	0°- 5°N	80°- 85°W	9-1
Off Ecuador	0°- 5°S	80°- 85°W	308-1

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[5]Monthly means of merchant ship injection surface temperatures made by the Pacific Environmental Group, NMFS, Monterey, CA 93940. Means by 5-degree squares are means of four submeans by 1-degree squares to reduce spatial bias effects. Data of 1931-71 are from Marine Deck (TDF-11), National Climatic Center, EDIS, Asheville, NC 28801, and data 1972-79 are from weather reports received by Fleet Numerical Oceanography Center, Monterey, CA 93940.

[6]Local climatological data. National Climatic Center, EDIS, Asheville, NC 28801.

REGIONAL CONDITIONS

Eastern Bering Sea

Surface Pressure - Persistence of a deep Aleutian low surface atmospheric pressure system south of the Alaska Peninsula during winter 1977-78 resulted in strong easterly winds over the eastern Bering Sea during January, February, and even March 1978. Winds weakened in the spring transition period, becoming southeasterly during April and northeasterly during May. A major shift to westerly wind velocity components occurred in June with generally southwesterly summer winds shifting to weak westerly winds by September. The Aleutian low reformed at the normal time, in October, over the Gulf of Alaska, but its center was shifted slightly westward towards the Bristol Bay area, bringing strong easterly to northeasterly winds over much of the Bering Sea coast. The low shifted far into the western Bering Sea in November, and remained there through January 1979, bringing anomalous warming with the associated strong, persistent, moist southwesterly winds contrasting markedly with the cool, dry continental easterlies of the previous year. In February 1979 the low divided into a split system which brought a return of easterly winds reminiscent of conditions in early 1978.

Ice - The extent of ice cover in winter and the timing of the ice breakup in spring can be determined from infrared images from orbiting satellites. Weekly charts of ice distribution issued by the U.S. Navy and the National Environmental Satellite Service, NOAA, provide information on ice conditions in the eastern Bering Sea. A graphical representation of the mid-month positions of the ice edge for the ice seasons of 1977-78 and 1978-79 is shown in Figure 9. For comparison, the position of maximum ice extent during the previous season (April 1977) is also shown.

Overall, the trend of decreasing ice cover observed in recent years continued, progressing from above normal ice cover in 1976 to below normal coverage in 1979. Some differences in ice development were evident compared to last year. The very rapid northward retreat of the ice edge in late spring (May-June) 1978 was followed by a very slow ice advance in autumn 1978. This was apparent in the one-month delay, November vs. December, in the southward advance of ice through Bering Strait to St. Lawrence Island. In addition to the delay, the December 1978 ice extent was much less than in 1977, and similar conditions persisted through January 1979. An abrupt advance of the ice edge occurred in February 1979 when it attained the same position as in February 1978. However, in Bristol Bay the seaward extent of ice exceeded that of the entire previous year even though it was apparently short-lived.

Temperature - Air temperatures over the eastern Bering Sea reflected the warming trend observed since 1977. Whereas unusually cold conditions had occurred during the period 1971-76, with two pairs of adjacent severe winters (1970-71, 1971-72 and 1974-75, 1975-76), recent conditions have been unusually warm. The warm conditions resulted from the predominantly southerly geostrophic winds observed over the area during much of the year. Large positive anomalies occurred in late 1978 and particularly in early 1979 due to the early shift of the center of the Aleutian low to the west and its persistence there for several months. At St. Paul Island, Pribilof Islands, air temperatures (Fig. 7) were above normal in all but four months during January 1977-May 1979 and 2.0°C or more above normal in 15 out of the 29 months of the period. The year 1979 will apparently be very warm on the average as air temperatures during January-May at St. Paul were 3.4°-4.7°C

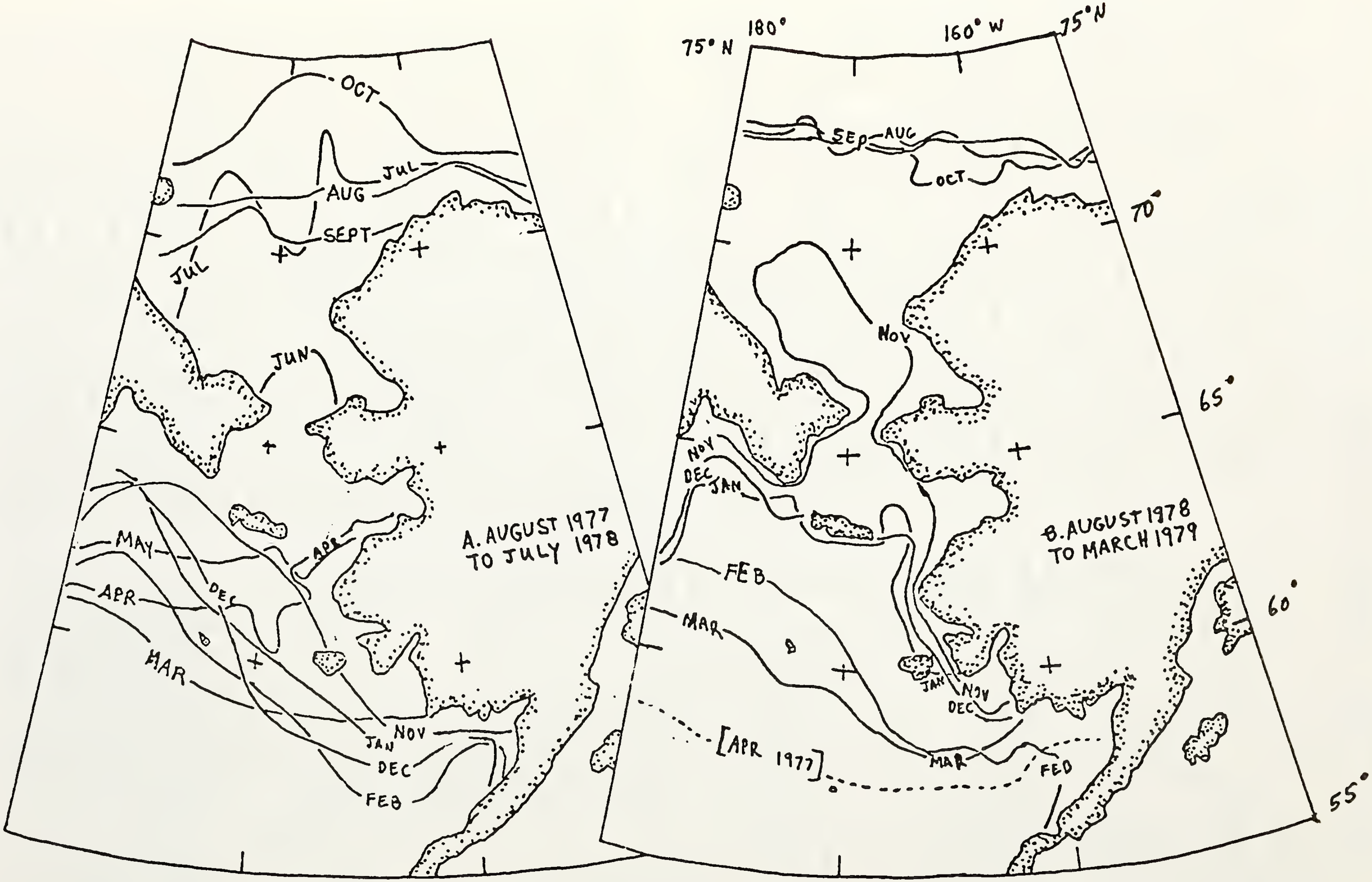

Figure 9.--Midmonth locations of the ice front in the eastern Bering and Chukchi Seas during August 1977-March 1979, and, for comparison, April 1977. Plotted from data of the National Environmental Satellite Service and from ice cover analyses from the U.S. Naval Polar Oceanography Center, Suitland, MD 20393.

above normal.

Sea surface temperature data from the area show trends similar to the air temperatures. At square 197-1 (Fig. 7) SST's were above normal during most months of the period June 1977-March 1979, although in contrast to the St. Paul air temperatures, SST's were warmest in 1977 and more moderate, but still above normal during 1978 and early 1979.

Bottom temperatures from the area did not show as clear a trend. Bottom temperatures in 1978 indicated the outer shelf area near the Pribilof Islands to be about 1°C warmer than in 1977 and the inner shelf area (near 57°30'N, 163°W) to be about 1°-2C° colder than in 1977. Although data for 1979 are not yet available, the extent and general wind conditions indicated that the bottom temperatures in 1979 will be anomalously warm and similar to 1978.

The timing and location of herring spawning in Bristol Bay may be related to water temperatures and ice conditions.[7] Cold conditions that existed in spring 1976 were associated with a shift of some herring spawning from the north shore to the south shore of Bristol Bay. Warm conditions in early 1979 caused herring spawning to be up to two weeks early, commencing in mid-April along the north shore of the bay.

Northward shifts in the distribution of herring and shrimp may also occur over the shelf near the Pribilof Islands in response to mild temperature conditions. In an area near the Pribilofs normally fished by foreign trawlers in winter, a survey by the Northwest and Alaska Fisheries Center in March 1978 found only trace quantities of herring. The absence of herring was explained by a northward shift in the distribution of stocks associated with warm water temperatures.[8] A similar survey for shrimp in June and early July 1978 in the same region found only low shrimp concentrations in regions of normally significant abundance. Relatively high catches were made only along the northwest edge of the survey area.[9]

Other species were probably affected by the recent mild conditions as well. Straty and Jaenicke[10] found faster growth rates of juvenile Bristol Bay sockeye salmon in a warm year, 1967, than a cold year, 1971. Possibly mortality of sockeye due to predation was higher in 1971 than 1967 due to the slower growth rates. Also cold conditions in 1971 and 1972 may have caused the 1971 seaward migrants to remain an extra year at sea. Warm conditions in recent years thus may result in rapid growth and low mortality of sockeye. The recent mild conditions may also result in stronger year classes of various flounders (such as yellowfin sole, rock sole, flathead sole, and Alaska plaice).[11]

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[7] Reported on page 25 of the Monthly Report for April 1979, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[8] Reported on page 27 of the Monthly Report for March 1978, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[9] Reported on page 25 of the Monthly Report for July 1978, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[10] Straty, R. R., and H. W. Jaenicke. Estuarine influence of salinity, temperature, and food on the behavior, growth, and dynamics of Bristol Bay sockeye salmon. Unpublished manuscript. Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[11] Reported on pages 25-27 of the Monthly Report for March, 1978, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

Pacific cod and Alaska pollock move onto the inner continental shelf in the eastern Bering Sea in summer months. During cold years, however, this movement is normally much less than during years with warmer temperatures (see footnote 11). Recent mild conditions would probably increase this inshore migration.

Runoff - The discharge of both the Yukon and Kuskokwim Rivers (Fig. 10) has a strong seasonal cycle with maximum discharge in summer (peaking in June) due to snow and ice melt, and minimum discharge in winter due to freezeup of the watersheds. The pulse of summer discharge has been below normal in recent years, particularly during 1974, 1976, and 1978. Although numerical data are not yet available for winter 1978-79, discharge during this period is reportedly about 10% greater than the previous year. Discharge of the Kvichak River, which is much more persistent in time than that of the Yukon or Kuskokwim Rivers due to the stabilizing effects of lakes in the watershed, was also below normal in 1974, 1976, and 1978.

Aleutian Islands to Icy Bay

Ice - Ice conditions in Prince William Sound and Cook Inlet were mild in both winters 1977-78 and 1978-79, and most bays were ice free by March of each year.

Temperature - Anomalies of sea surface temperatures along the southwest coast of Alaska are presented as time-distance matrices in Figure 11. In Marsden 5° square 197-1 (Fig. 7) south of the Peninsula, SST's had been below normal during 1971 to 1976 with the exception of fall 1974. Temperatures became anomalously warm in summer and fall 1977 and have been more nearly normal since then. Farther east at the head of the Gulf of Alaska (square 195-3, Fig. 7) SST's were generally similar, but were slightly below normal in 1978 and 1979.

During January-May 1978 SST's from Unimak Pass to Kodiak Island (Fig. 11) were above normal, became below normal during summer and early fall 1978, and were mixed the remainder of the period. SST's off Prince William Sound were colder than normal throughout 1978 and early 1979 as indicated at square 195-3.

Although historical bottom temperature data are sparse for this area, it is possible to compare bottom temperature regimes for the mid-shelf (about 50-150 m depth) near Kodiak Island for the period late winter-early spring for three consecutive years: 1976, 1977, and 1978 (using data collected on OSCEAP cruises) and also during the cold year 1972 (from a NWAFC cruise). Bottom temperatures of about $2^{\circ}C$ occurred off Kodiak Island in May 1972, whereas mid-shelf temperatures in 1976, 1977, and 1978 were 2°-$3^{\circ}C$ warmer ($3.7^{\circ}C$, $5.7^{\circ}C$, and $4.5^{\circ}C$, respectively). It is interesting to note that during the warm year, 1977, the permanent subsurface $5^{\circ}C$ temperature maximum at about 250 m, associated with warm westward advection in the Alaskan Stream just seaward of the shelf break, was not clearly discernible for the first time.

Runoff - Several rivers flow into Cook Inlet, and the resulting dilute surface water flows southwestward through Shelikof Strait, north of Afognak and Kodiak Islands. However, the major river discharge at the head of the Gulf of Alaska is from the Copper River. Like the Yukon and Kuskokwim, the Copper River has a strong seasonal cycle with minimum discharge in winter and maximum discharge in summer, peaking in July (Fig. 10). At the time of this writing, data were available only through September 1978 and indicated above normal discharge in 1978.

Salinity - Further information on the surface salinity minima area reported last year for 1977 (McLain et al. 1979) is now available for late

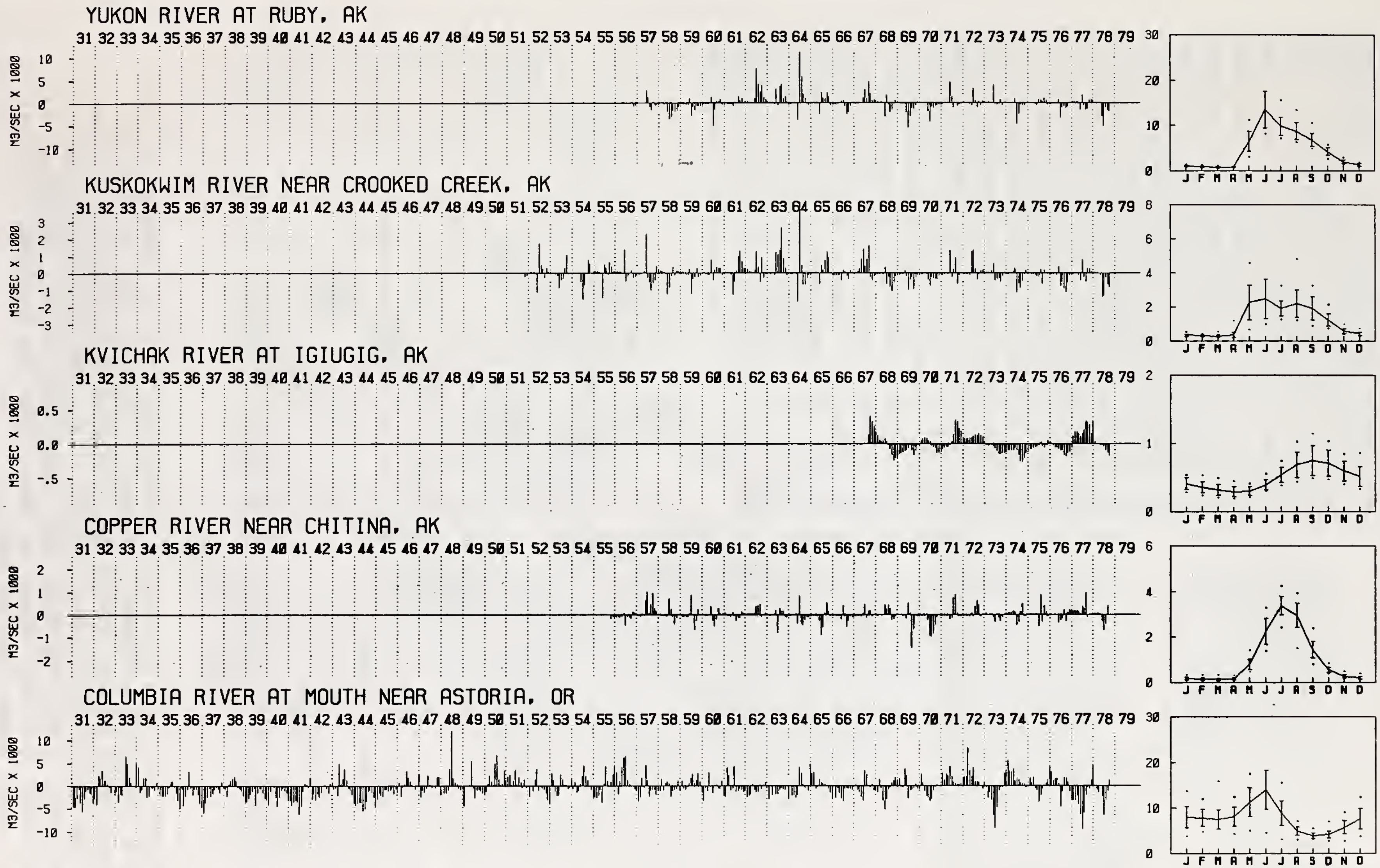
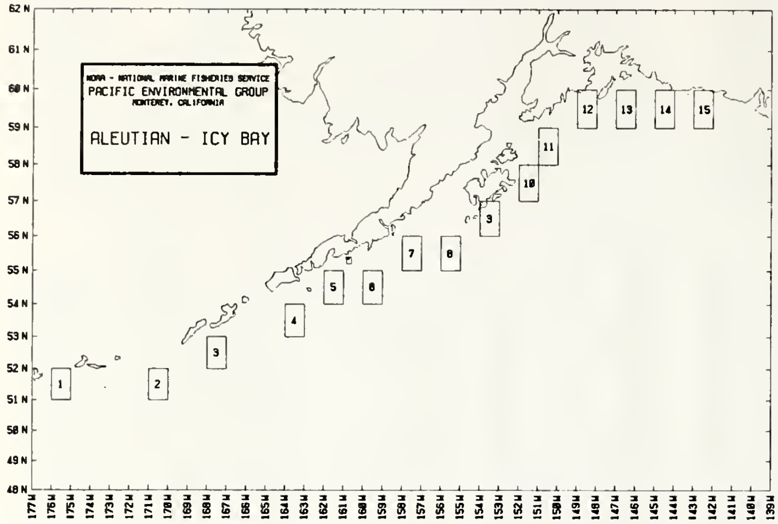
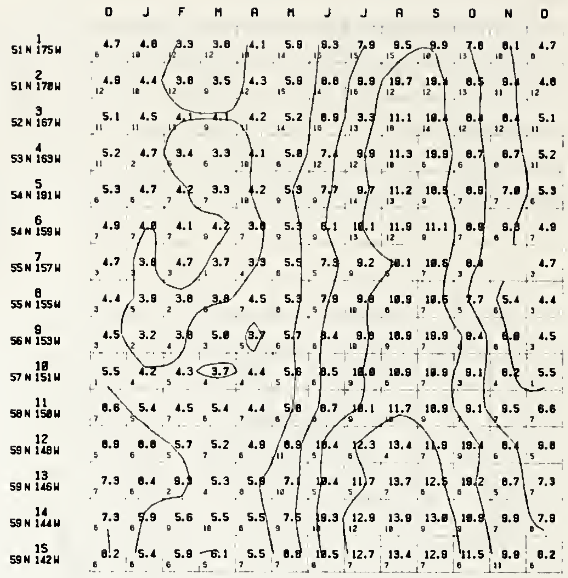


Figure 10.--Time series for 1931-79 of anomaly of river discharge into the ocean in thousands of cubic meters per second from the long-term mean reference period 1948-78. This is a different reference period than the 1948-67 period used in the remainder of the text to allow computation of a mean for the Kvichak River for which data start in 1967. Data from U.S. Geogological Survey. Data for Columbia River are extrapolated to the mouth of the river from observations upstream.





SEA SURFACE TEMPERATURE   LONG TERM MEAN 1971-1978

	1978 J	F	M	A	M	J	J	A	S	O	N	D	1979 J	F	M
1 51N 175W	-.5 3	-.2 4	0.6 3	0.1 2	-.0 5	0.7 2	-1.9 5	0.5 1		-.3 2	-.1 2	0.8 1	-1.4 2	1.1 1	-.8 1
2 51N 170W		0.6 2	0.1 3	1.2 2	0.5 10	0.6 3	-1.1 4	0.3 2	1.7 1				-.4 2	0.5 1	
3 52N 167W		1.1 2	-.6 2	1.5 5	0.6 4	1.5 3	-2.3 1	-1.4 1		1.6 1				-.1 1	0.4 1
4 53N 163W	-.9 1	-.1 4	0.8 2	-.2 2	-.5 7	2.1 1	1.1 2	-1.0 3	0.3 2		1.6 3		-.9 1	-.4 1	
5 54N 161W	0.2 13	0.6 19	1.3 20	-.1 23	-.8 51	0.1 7	-1.0 13	-.2 8	0.7 5	0.2 3	0.5 3	-.3 1	0.1 5	-1.0 5	1.0 13
6 54N 159W	0.1 12	-.1 14	-.0 21	0.5 89	-.1 42	-1.5 11	-.9 21	-1.1 4	-.5 6	-1.3 4	1.5 5	2.0 3	1.0 4	-1.0 5	-.0 12
7 55N 157W	2.1 1	-.3 4	0.7 8	0.4 10	-.1 41	-.6 33	0.7 4	0.7 1	-.3 2				2.0 2	-2.5 1	
8 55N 155W	-.0 5	0.8 46	1.7 2	0.6 5	1.5 9	-.3 19	-.9 1	-.2 4	-.7 2	1.8 1	1.1 3	1.8 1	0.9 2	0.2 1	1.2 1
9 56N 153W	1.9 49	-.1 4	-.1 5	0.8 8	0.4 11	-.5 43	-1.1 12	0.5 2	0.5 5	-.5 5	0.9 12		0.9 5	-.3 2	
10 57N 151W	0.2 78	0.0 129	0.4 191	-.1 147	-.1 3	-.2 16	-1.6 12	-.7 31	-2.3 64	-2.3 89	-1.0 126	-1.3 149	-.5 74	0.2 3	0.0 4
11 58N 150W	0.2 2	-.2 12	-.8 7	0.3 5	0.3 14	-.7 12	0.8 3	0.9 3	-.2 1	-.7 5	0.6 9	-1.0 1	-2.1 1	-.4 4	-.5 5
12 59N 148W		-1.6 3			-1.2 3	-.8 5	-.9 2							-1.7 3	
13 59N 146W	-1.5 8		0.8 1	-2.6 1	0.1 2	-.1 2			-.8 1			-2.3 1			
14 59N 144W	-1.8 3	-1.3 5	0.0 1	0.7 5	-2.0 13	-2.4 7	-1.7 4	-.8 8	-2.4 2	-1.8 6	-2.0 6	-1.7 4	-1.1 7	-1.2 5	
15 59N 142W	0.7 1				-1.6 1		-1.5 2	-.3 2							

Figure 11.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from the Aleutian Islands to Ice Bay (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 28801.

summer 1978.[12] A marked seaward penetration of a low-salinity (31.6‰) plume from the Copper River area (Fig. 12) extending 80 km south of the shelf break well into the oceanic regime of high-salinity (>32.6‰) water was discovered. The seaward terminus of the plume reflected an anomalous eastward movement near the origin of the westward flowing boundary current, the Alaskan Stream. It is now evident that two sources of dilution, the Copper River in the northern Gulf and a tongue of low-salinity water from in the eastern Gulf, can contribute on a year-round basis to an anomalous offshore salinity minima area east of Kodiak Island (Ingraham 1979). Thus considerable complexity in surface flow is implied by the surface salinity distributions of 1977 and 1978. This may have considerable influence on the variability of the transport of ichthyoplankton, particularly halibut larvae, as well as on the seaward migration path of salmon smolts from southeast Alaska, British Columbia, Washington, and Oregon.

Icy Bay to Strait of Juan de Fuca

Temperature - Sea-surface temperatures along the coast of southeast Alaska and British Columbia (square 157-4; Fig. 7) were below normal from mid-1970 until mid-1976 (except for fall 1974), warmer than normal during early 1977 and early 1978, and colder than normal in early 1979. SST's plotted as time-distance matrices (Fig. 13) reflected the same pattern in 1978 but in greater detail: warmer than normal in early 1978, mixed until October, and colder than normal during November 1978-March 1979 (particularly at the southern end of the area off Vancouver Island).

Related bottom temperature data are sparse, but Douglas and Wickett (1978) found bottom temperatures up to about 2°C above normal off Vancouver Island during a groundfish survey in early March 1978. SST's at that time and location were about 0.8°C above normal (Fig. 13).

Surface and subsurface temperature data in the inside passages of southeastern Alaska during winter are available for the last three years from expendable bathythermograph (XBT) observations at 13 stations from Dixon Entrance northwards to Juneau.[13] Temperatures at the southern stations of the series are normally higher both at the surface (Fig. 14a) and at 90 m depth (Fig. 14b) than those at the northern stations. This is consistent with past SST's taken at Coast Guard lighthouses during the period 1959-74. Monthly mean SST data are not available from the lighthouses for the 1977-79 period; however, the 1979 XBT surface temperature observations are in the lowest 20 of observations from other available SST data sources for late January-early February. The cooling trend of the past two years is reflected in the late winter temperatures taken at 90 m at the 13 stations where the 1977 temperatures averaged 0.7°C higher than those in 1978 and the 1979 temperatures averaged 1.5°C lower.

Salinity - Measurements of surface salinity were made off the coast from Icy Bay to southeastern Alaska during summer 1977 by the Polish research vessel, Professor Siedlecki, and during summer 1978 by the NOAA research vessels, Miller Freeman and Oceanographer. The distributions of surface

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[12] Cruise No. 78-03, RV Miller Freeman, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[13] XBT observations made from RV John N. Cobb and provided by R. R. Straty, Northwest and Alaska Fisheries Center, NMFS, Auke Bay, AK 99821.

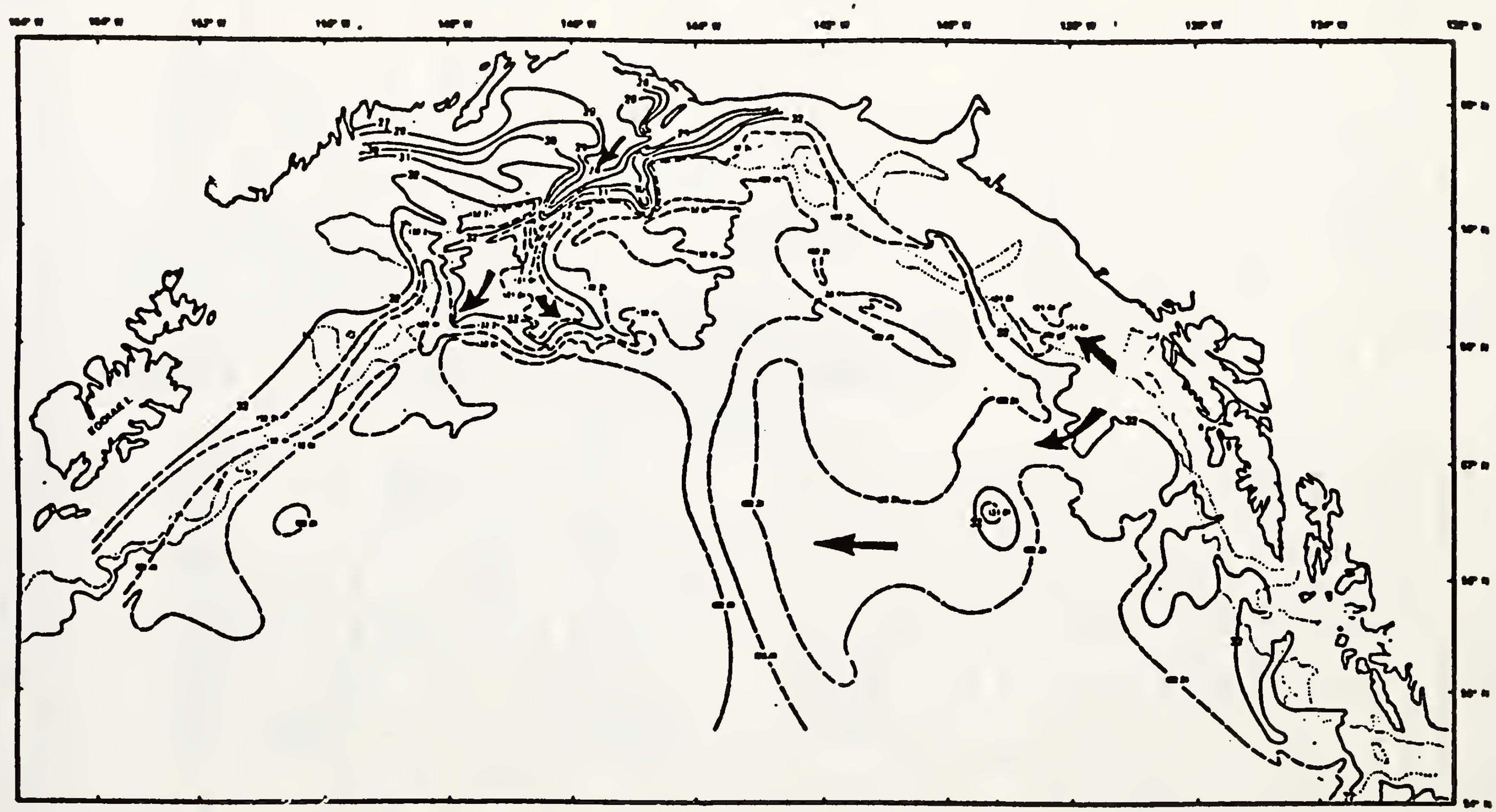
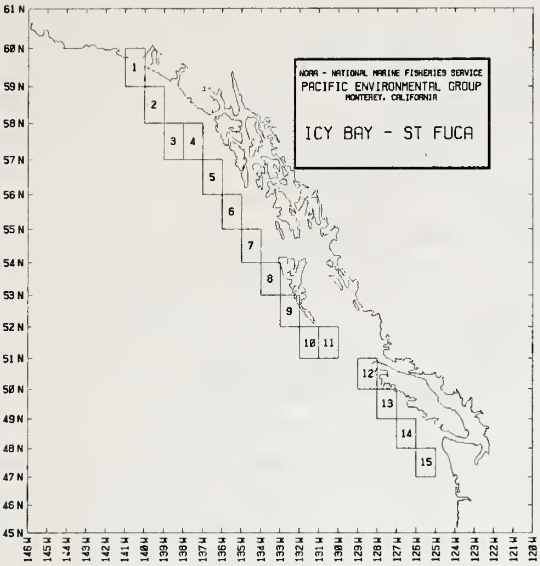


Figure 12.--Surface salinity in parts per thousand for summer 1978. Data were obtained from the NOAA research vessel (RV) Miller Freeman, the University of Alaska RV Acona, the Korean RV Oh Dae San, and the NOAA RV Oceanographer.



	D	J	F	M	A	M	J	J	A	S	O	N	O
1 59 N 140 W	6.1 (1)		5.7 (3)	3.7 (1)	5.8 (3)	6.6 (3)	12.1 (2)	16.1 (1)	13.6 (2)		10.0 (1)	8.7 (2)	6.1 (1)
2 58 N 139 W	7.4 (9)	6.2 (5)	6.1 (8)	6.4 (7)	5.6 (7)	7.1 (5)	11.4 (5)	10.9 (4)	14.4 (5)	12.8 (6)	10.8 (9)	8.9 (9)	7.4 (9)
3 57 N 138 W	7.9 (6)	7.1 (7)	6.3 (7)	6.0 (12)	6.0 (10)	8.3 (6)	10.6 (7)	13.4 (6)	14.7 (7)	13.9 (11)	10.9 (9)	9.2 (8)	7.9 (6)
4 57 N 137 W	7.9 (7)	6.1 (6)	7.0 (4)	6.4 (5)	5.2 (3)	7.7 (5)	10.8	11.7 (4)	12.6 (3)	14.2 (3)	10.8 (4)	9.6 (6)	7.9 (7)
5 56 N 136 W	8.3 (8)	7.1 (9)	6.7 (7)	7.2 (9)	6.9 (7)	8.0 (8)	11.6 (10)	13.2 (9)	14.5 (8)	13.7 (10)	11.3 (9)	9.4 (8)	8.3 (8)
6 55 N 135 W	8.4 (7)	8.1 (7)	7.6 (6)	7.6 (8)	7.6 (9)	9.3 (12)	11.5 (9)	12.2 (10)	14.6 (10)	13.5 (10)	11.5 (8)	10.7 (8)	8.4 (7)
7 54 N 134 W	7.9 (4)	7.0 (6)	7.1 (5)	6.6 (4)	6.4 (6)	8.8 (5)	11.0 (5)	11.6 (7)	14.7 (4)	13.8 (5)	11.6 (3)	10.1 (3)	7.9 (4)
8 53 N 133 W	7.7 (3)	6.9 (2)	7.5 (4)	7.2 (4)	7.1 (2)	8.9 (3)	10.8 (6)	12.3 (5)	15.1 (8)	13.0 (4)	12.4 (2)	9.6 (2)	7.7 (3)
9 52 N 132 W	8.0 (5)	7.8 (5)	7.3 (6)	7.6 (8)	7.7 (6)	9.2 (8)	10.5 (8)	13.0 (9)	15.0 (8)	14.0 (8)	11.7 (4)	8.8 (5)	8.0 (5)
10 51 N 131 W	8.6 (8)	7.6 (10)	7.7 (7)	7.2 (11)	7.8 (6)	9.6 (8)	11.1 (7)	12.2 (6)	14.7 (8)	13.9 (9)	12.5 (5)	9.4 (7)	8.6 (8)
11 51 N 130 W	8.7 (5)	7.8 (4)	8.0 (4)	7.5 (5)	7.9 (6)	9.3 (6)	11.5 (5)	12.7 (9)	14.9 (7)	13.6 (5)	11.5 (4)	9.9 (5)	8.7 (5)
12 50 N 128 W	10.2 (4)	8.5 (3)	9.0 (2)	7.1 (4)	8.2 (5)	9.6 (2)	12.1 (5)	12.5 (6)	14.7 (5)	13.8 (4)	11.9 (3)	10.5 (8)	10.2 (4)
13 49 N 127 W	9.0 (11)	8.9 (6)	8.3 (10)	8.2 (11)	9.3 (12)	10.3 (12)	12.1 (12)	13.5 (14)	15.1 (12)	14.9 (13)	12.8 (9)	10.8 (14)	9.0 (11)
14 48 N 126 W	9.1 (15)	8.4 (14)	8.0 (14)	7.8 (15)	8.7 (17)	10.5 (15)	12.2 (17)	13.4 (13)	14.8 (17)	14.3 (16)	13.2 (16)	10.9 (16)	9.1 (15)
15 47 N 125 W	9.7 (13)	9.1 (15)	9.4 (16)	9.0 (15)	9.3 (17)	11.3 (11)	14.0 (13)	14.7 (11)	15.6 (12)	15.2 (13)	13.6 (14)	11.6 (17)	9.7 (13)

SEA SURFACE TEMPERATURE LONG TERM MEAN 1971-1978

	1978												1979		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1 59 N 140 W															
2 58 N 139 W	0.1 (6)				0.8 (1)	-.3 (2)	2.1 (1)	-1.6 (1)	0.6 (1)						-1.5 (5)
3 57 N 138 W	-1.0 (1)	-1.3 (1)					0.4 (1)					-1.2 (1)			
4 57 N 137 W	-.2 (3)				-2.3 (3)	0.1 (3)	0.8 (2)		0.2 (1)						
5 56 N 136 W		-.5 (2)			2.0 (1)	-1.1 (1)				-1.1 (1)					-1.2 (1)
6 55 N 135 W	-.9 (1)	-.5 (2)				-1.0 (2)									-1.3 (2)
7 54 N 134 W	1.9 (1)	0.1 (4)	-.2 (3)	1.6 (1)		0.1 (1)	0.8 (1)	-1.4 (2)			0.5 (1)	-.9 (1)	-.1 (2)		
8 53 N 133 W	2.1 (1)	-2.0 (2)	1.1 (2)	0.7 (3)	-1.2 (1)		0.3 (5)	-1.2 (4)	0.4 (1)	1.0 (1)		-.1 (3)	-.7 (2)	-.7 (3)	-1.0 (2)
9 52 N 132 W	-.3 (5)	0.1 (8)	-.1 (4)	1.3 (4)	-.9 (7)	1.0 (5)	-.3 (13)	-1.1 (7)	-.7 (3)	0.1 (7)	0.9 (6)	0.1 (6)	-.9 (5)	0.1 (7)	-1.6 (4)
10 51 N 131 W	0.9 (3)	-1.0 (2)	1.0 (11)	0.2 (16)	-.2 (8)	-.6 (5)	1.1 (11)	-1.5 (4)	-.5 (1)	-1.0 (7)	0.7 (7)	0.3 (9)	-.4 (5)	-1.1 (11)	-.1 (5)
11 51 N 130 W	0.4 (2)	0.1 (7)	1.2 (2)	1.3 (10)	0.8 (9)	0.7 (7)	-.2 (8)	-.5 (6)	0.0 (6)	1.0 (2)	0.1 (5)	-.2 (4)	-.6 (3)	-2.3 (4)	-.4 (10)
12 50 N 128 W	0.2 (6)	-1.4 (5)	1.1 (4)	1.1 (9)	1.0 (5)		0.4 (7)	-1.6 (2)	0.1 (2)	0.2 (8)	0.6 (2)	-3.0 (1)	-.5 (1)		0.4 (4)
13 49 N 127 W	0.2 (12)	-.3 (10)	0.8 (14)	0.1 (12)	0.9 (18)	-1.1 (4)	-2.1 (6)	-.9 (2)	0.1 (3)	-.1 (10)	-1.0 (5)	-.1 (4)	-1.7 (15)	-1.4 (6)	-.5 (12)
14 48 N 126 W	1.5 (7)	-.2 (4)	-.2 (14)	0.3 (3)	1.1 (19)	0.9 (10)	0.0 (4)	0.6 (29)	0.0 (5)	1.0 (3)	0.2 (4)	0.3 (11)	-1.3 (10)	-1.2 (3)	-.0 (7)
15 47 N 125 W	-1.4 (3)	-.3 (8)	0.4 (5)	0.8 (5)	0.7 (16)	0.6 (60)	-.9 (74)	-.2 (7)	0.3 (6)	1.7 (2)	-2.5 (2)	-1.1 (2)	-1.4 (5)	-1.9 (8)	0.5 (14)

Figure 13.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from Icy Bay to the Strait of Juan de Fuca (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 28801.

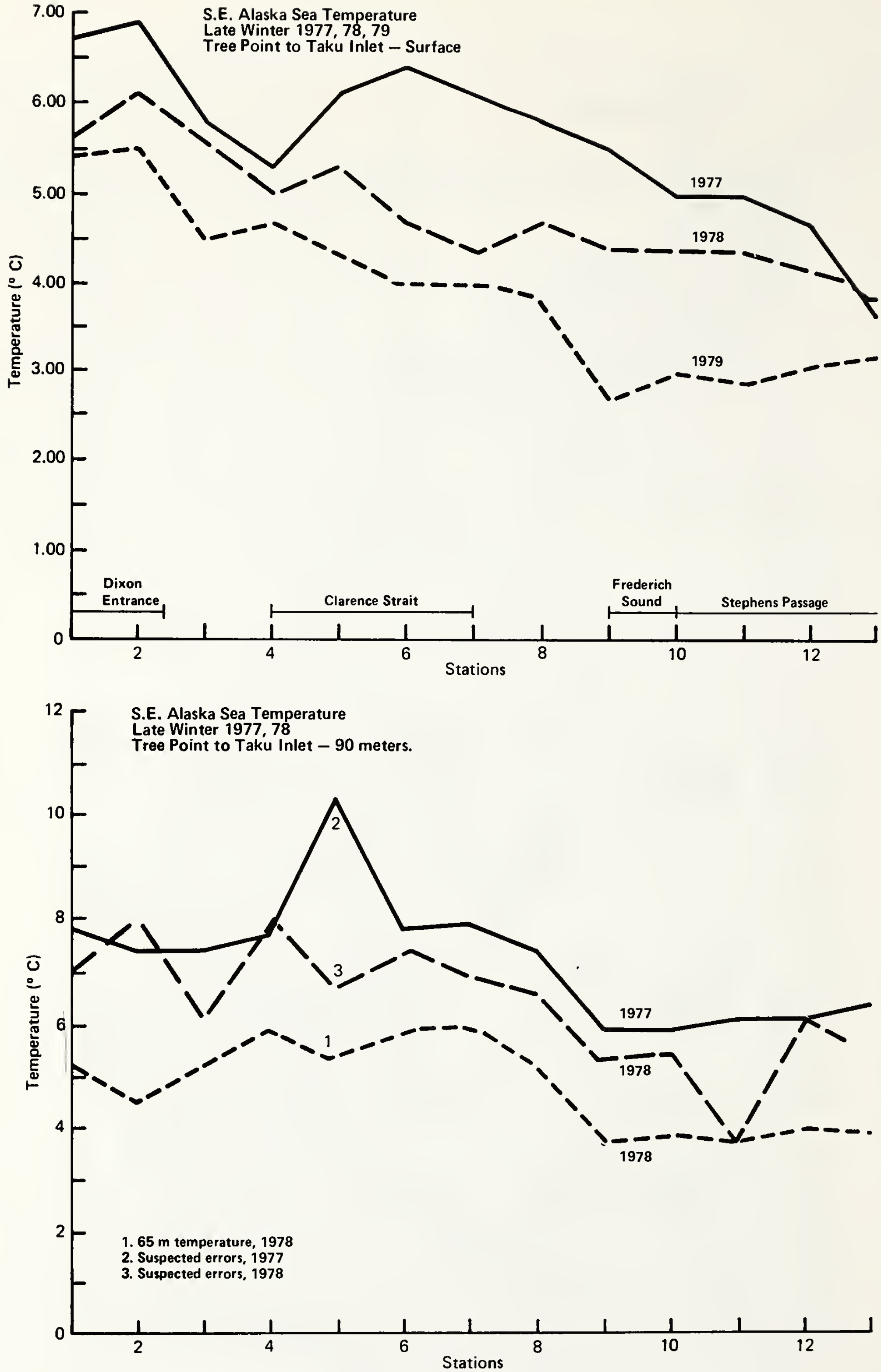


Figure 14.--a. Sea-surface temperature in degrees Celsius for late winter 1977, 1978, and 1979 from Tree Point to Taku Inlet, Alaska (upper).

b. Temperature at 90 m in degrees Celsius for late winter 1977 and 1978, and at 65 m depth in 1978 from Tree Point to Taku Inlet (lower).

Figures supplied by J. Ingraham, Northwest Fisheries Center, NMFS, Seattle, WA 98112.

salinity indicated that, north of 58°N, the trend of the isohalines was northwesterly and parallel to the shoreline, apparently reflecting longshore processes in the absence of major freshwater sources. South of 58°N tongues of dilute water (<32.0°/oo) extended about 100 km seaward near local sources of runoff. The major feature, reported for the first time in 1977 and again evident in 1978, was the bifurcation in coastal flow near 58°N. This bifurcation was evident as a tongue of low-salinity (<32.0°/oo) water pointing toward the northwest in 1977, but in 1978 the major tongue had a salinity of about 0.2°/oo higher and the axis of the tongue trended more perpendicular to shore in a westward to southwestward direction (Fig. 12). Near 55°N a wide band of water with a salinity less than 32.4°/oo suggested that the extent of the major effects of coastal dilution was about 100 km farther seaward in 1978 (142°W). True oceanic salinities of 32.6°/oo were not encountered until nearly mid-Gulf (about 144°W) during both years.

Coastal Circulation - As has been mentioned, in late 1977 and early 1978 onshore Ekman transport was stronger and more toward the northeast than normal along the coast of southeastern Alaska and British Columbia. As a result, the northward flow of the Gulf of Alaska Gyre was intensified and SST's were above normal. Douglas and Wickett (1978) attributed the above normal bottom temperatures off Vancouver Island in early 1978 to stronger than normal onshore Ekman transport of warm surface waters from the southwest with convergence and sinking of surface water at the coast.

Numerous unusual biological events were observed in the area, although their relation to the onshore transport is as yet poorly understood. These included failure of the acorn barnacle, Balanus cariosus, to settle during its normal winter settling season; accentuated settlement and growth of two other barnacle species during the winter months (both of these species usually are most vigorous during a July-October interval); accentuated algal growth on the shore (diatoms especially, but also Ulva and Nereocystis); a massive incursion, on shore, of salps in unheard of quantity; numerous comments by fishermen of blue sharks in very close to shore and in unusual abundance; and finally, unusually few Japanese glass floats coming ashore.[14]

Reports from salmon trollers[15] confirm the massive intrusion of salps off southeastern Alaska in summer 1978 and also the occurrence then of saury and sea turtles (leatherbacks). Both of the latter species normally occur in offshore waters to the south and thus may have been transported to coastal waters of southwestern Alaska by anomalous northward, onshore transport. Wickett[16] suggested that "the early strong Ekman transport to the northeast is associated with the unprecedented large percentage (70) of adult Fraser River sockeye that returned to the river through Queen Charlotte Strait instead of using the Straits of Juan de Fuca." Part of the mechanism is believed to be a northern displacement of a plume of low-salinity water from

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[14]These observations were made by Dr. R. T. Paine and his graduate students of the Department of Zoology, University of Washington, Seattle, WA 98195, at a site near the tip of the Olympic Peninsula in Washington and at Glacier Bay, Alaska (Lasker 1978).

[15]B. L. Wing, Northwest and Alaska Fisheries Center, NMFS, Auke Bay, AK 99821. Personal communication.

[16]P. Wickett. Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada. Personal communication.

Queen Charlotte Sound (cf. Fig. 12). The herring roe fishery in Barkley Sound just inshore of the survey area reported on by Douglas and Wickett (1978) was disrupted by the unusual behaviour of the fish which spawned at greater than normal depths."

Adult pink salmon returns to Little Port Walter Bay, Baranof Island, in southeastern Alaska in 1978 had an unusually high ocean survival (Herd 1979). However, this was probably more related to conditions in 1977 when salmon fry entered the ocean than in 1978 when the adults returned.

Strait of Juan de Fuca to Gulf of California

Temperature - Anomalies of sea-surface temperature along the west coast of the United States had somewhat similar trends as in areas to the north. At square 121-3 (Fig. 7) off central California, SST's have been below normal almost continuously since mid-1970 with short above normal periods in mid-1977 and early 1978. At squares 120-2 off southern California and 83-2 off the Gulf of California, the basic pattern of variation was similar to that at square 121-3 except that it was shifted to slightly more positive anomalies. Thus at squares 120-2 and 83-2, SST's were below normal in early 1971 and 1972 and again in 1973 and 1975, above normal in late 1976 and early 1978, and near normal values in late 1979.

Figures 15 and 16 give more details on SST variations along the coast during 1978 and early 1979. Along the California coast, north of Point Conception (34^{o}-40^{o}N; Fig. 15) SST's were anomalously warm during early 1978 during the period of extreme low upwelling, but fell to below normal levels in June. Farther north (41^{o}-48^{o}N) the above normal SST's persisted until November when anomalous cooling became evident. SST's were uniformly below normal during winter 1978-79 and the anomalies were generally negative by 1^{o}-2^{o}C. By March 1979 SST's returned to normal values.

Along the coast of southern California and Baja California (Fig. 16), the fluctuations of SST were similar to those observed to the north. Above normal SST's occurred in early 1978 and persisted until summer and early fall when anomalous cooling occurred. SST's were below normal off Baja California in fall and into winter 1978-79, but were again near normal in March 1979.

Runoff - Maximum mean monthly runoff of the Columbia River[17] into the ocean normally occurs in June and minimum discharge normally occurs in September. However, the seasonal variation of runoff can vary markedly from year to year. For example, in 1977 minimum monthly mean discharge occurred in July (McLain et al. 1979) and the maximum (roughly four times the minimum) occurred in December. These variations were caused by drought during most of 1977 and heavy precipitation in winter 1977-78.

Conditions in 1978 indicated a return to more normal trends with some exceptions. Above normal runoff continued through March 1978 (Fig. 10). The maximum discharge occurred in May 1978, rather than June, and the June discharge was nearly 50 less than normal.

Coastal Circulation - During January-March 1978 southerly winds occurred over California during anomalous high pressure and drought conditions. As has been mentioned, upwelling during this period was extremely low (Fig. 5)

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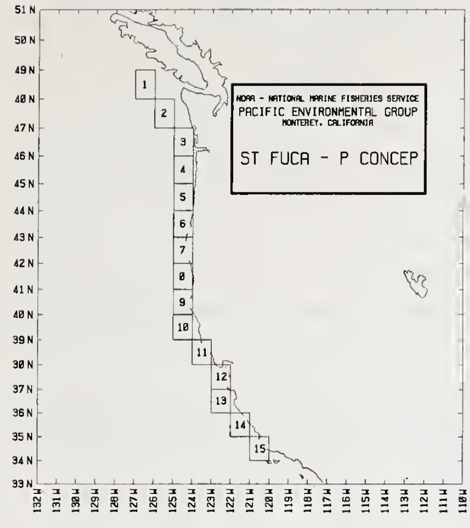
[17] S. F. Kapustka, U.S. Geological Survey, Portland, OR 92708. Personal communication.

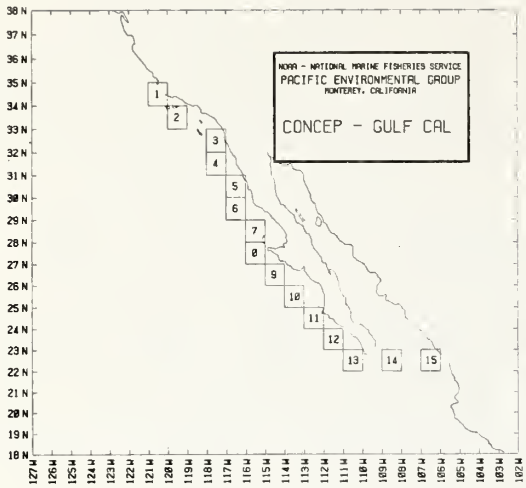


	D	J	F	M	A	M	J	J	A	S	O	N	D
1 48N 126W	9.1 15	8.4 14	8.0 14	7.8 15	8.7 17	10.5 15	12.2 17	13.4 13	14.0 17	14.3 16	13.2 16	10.9 16	9.1 15
2 47N 125W	9.7 13	9.1 15	9.4 16	9.0 15	9.3 17	11.3 11	14.0 13	14.7 11	15.6 12	15.2 13	13.6 14	11.6 17	9.7 13
3 46N 124W	10.3 9	9.7 9	9.2 14	9.0 15	10.0 14	11.9 13	13.0 14	15.0 14	15.7 14	15.4 14	13.5 13	12.0 15	10.3 9
4 45N 124W	10.0 12	9.9 14	9.6 13	9.5 18	10.2 16	11.0 17	13.9 16	14.0 13	15.8 17	15.3 17	13.9 14	12.0 16	10.0 12
5 44N 124W	11.1 17	10.2 13	9.9 18	9.7 18	10.2 17	11.2 16	13.6 16	14.0 14	14.5 15	14.6 14	14.0 17	12.1 14	11.1 17
6 43N 124W	11.1 16	10.6 15	10.1 14	9.8 17	10.5 18	11.5 16	13.0 16	13.1 15	13.0 12	14.0 18	13.3 13	12.1 16	11.1 16
7 42N 124W	11.7 17	10.5 14	10.5 15	10.5 18	10.4 17	11.4 17	11.9 16	11.8 16	12.6 14	13.3 18	13.1 17	12.6 16	11.7 17
8 41N 124W	11.9 17	11.0 15	10.7 16	10.6 18	10.6 17	11.3 18	12.[illegible] 18	11.9 16	12.3 16	13.0 18	12.0 16	12.2 17	11.9 17
9 40N 124W	12.3 17	11.1 15	10.0 16	10.0 18	10.0 17	11.0 18	11.0 18	12.0 17	12.7 14	13.2 17	13.2 17	12.6 18	12.3 17
10 39N 124W	12.7 19	11.5 20	11.4 18	11.1 20	10.7 20	11.6 20	12.1 20	12.6 20	12.9 20	13.7 19	13.5 19	13.3 20	12.7 19
11 38N 123W	12.0 19	11.6 19	11.6 19	11.4 20	11.3 20	11.6 20	12.0 20	12.6 19	13.5 20	13.7 18	14.0 20	13.5 20	12.0 19
12 37N 122W	12.7 19	12.2 19	12.3 18	12.2 20	12.1 18	12.7 19	13.6 20	14.2 19	14.6 20	15.0 20	15.2 19	14.0 20	12.7 19
13 36N 122W	13.7 19	12.0 20	12.4 19	12.3 20	12.4 20	12.7 20	13.5 20	14.3 20	14.6 20	15.6 20	15.1 19	14.3 20	13.7 19
14 35N 121W	13.9 20	12.9 20	12.9 20	12.7 20	12.5 20	12.5 20	13.5 20	14.3 20	14.9 20	15.6 20	15.5 20	14.0 20	13.9 20
15 34N 120W	14.4 19	13.6 20	13.4 19	12.9 20	12.9 19	13.2 20	14.0 20	15.5 20	16.1 17	16.6 20	16.1 20	15.4 20	14.4 19

SEA SURFACE TEMPERATURE LONG TERM MEAN 1971-1978

	1978												1979		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1 48N 126W	1.5 7	-.2 4	-.2 14	0.3 3	1.1 19	0.9 10	0.0 4	0.6 29	0.0 5	1.0 3	0.2 4	0.3 11	-1.3 10	-1.2 3	-.0 7
2 47N 125W	-1.4 8	-.3 8	0.4 5	0.8 5	0.7 16	0.6 60	-.9 74	-.2 7	0.3 6	1.7 2	-2.5 2	-1.1 2	-1.4 5	-1.9 6	0.5 14
3 46N 124W	0.2 220	0.6 240	0.6 253	-.3 229	-.5 16	2.2 13	-.7 173	-1.0 35	-.3 152	0.7 170	-.4 168	-.3 205	-2.0 128	-2.4 203	-.8 249
4 45N 124W	0.3 5	0.7 0	1.4 5	0.7 10	0.5 7	1.9 118	0.2 54	0.1 12	0.9 14	1.4 17	-1.5 6	-1.4 4	-1.0 1	-1.2 3	0.4 6
5 44N 124W	0.5 5	1.5 11	2.0 5	1.3 6	0.7 13	1.6 218	-.5 170	0.2 76	0.9 36	1.4 23	0.2 10	-.6 4	-1.4 6		1.0 10
6 43N 124W	0.3 3	1.1 13	1.9 8	0.7 3	0.4 5	1.3 83	0.5 118	0.9 105	2.0 47	1.2 0	-.7 2	-2.0 8	-1.2 7	-1.8 3	-.6 11
7 42N 124W	1.5 3	0.8 5	0.7 5	0.6 0	1.0 4	2.1 27	1.1 27	0.1 9	2.2 3	-1.4 1	-.1 6	-.5 3	-.5 7	-2.0 5	-.9 6
8 41N 124W	0.5 4	0.4 10	2.0 7	0.8 12	1.3 5	1.1 127	0.4 153	1.4 6	2.0 6	1.7 2	2.6 11	-1.9 5	-1.5 5	-2.0 4	-.2 19
9 40N 124W	1.0 6	1.7 11	1.5 7	1.3 13	0.9 12	0.7 50	-.3 47	0.2 9	0.0 3	1.5 5	-.4 13	-2.1 10	-.4 8	-1.8 5	0.6 19
10 39N 124W	0.7 11	1.2 17	1.4 8	1.6 21	0.3 13	-.1 10	0.5 7	0.5 10	0.4 7	-.5 8	-1.5 14	-2.3 14	-.7 12	-1.4 10	0.3 31
11 38N 123W	1.3 6	1.2 8	0.4 4	1.2 10	-.1 9	-.2 14	-.2 7	0.6 12	0.8 6	0.1 6	-1.5 9	-1.5 12	-.7 4	-.9 6	0.1 26
12 37N 122W	1.4 2	0.1 0	0.2 4	1.3 7	-.5 5	-1.1 2	-1.8 2	0.8 5	-1.6 5	0.1 2	0.2 3	-.6 5	-.4 6	-2.0 3	-1.3 8
13 36N 122W	0.5 9	0.6 14	1.3 10	0.9 10	-.5 10	-1.6 13	-1.1 25	0.6 12	-.7 9	0.4 5	-1.6 13	-1.9 35	-1.0 13	-1.6 7	0.1 24
14 35N 121W	0.8 12	0.7 15	1.5 17	0.7 16	-.4 19	-1.0 7	0.5 14	-.8 10	-1.4 14	-1.4 5	-.5 13	-.9 11	-1.1 13	-1.1 14	0.3 16
15 34N 120W	2.0 1	-1.5 5	2.0 8	-.3 6	0.4 12	-1.6 5	-2.4 8	-.4 7	-.9 5	1.1 3	0.4 9	-.3 7	-1.2 0	-.4 4	-.9 0

Figure 15.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from the Strait of Juan de Fuca to Point Conception (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 22801.



	D	J	F	M	A	M	J	J	A	S	O	N	D
1 34 N 120 W	14.4	13.6	13.4	12.9	12.9	13.2	14.0	15.5	16.1	18.6	16.1	15.4	14.4
2 33 N 119 W	15.0	14.4	14.3	14.3	14.4	15.0	15.9	17.6	18.6	18.7	18.3	16.6	15.8
3 32 N 117 W	16.4	14.9	14.7	15.0	15.7	16.2	17.2	19.0	20.0	19.0	19.1	17.6	16.4
4 31 N 117 W	16.7	15.6	15.1	15.1	15.7	16.4	17.1	18.5	20.0	20.0	19.2	17.9	16.7
5 30 N 116 W	17.1	15.9	15.6	15.4	15.0	16.2	16.0	18.5	19.9	20.2	19.4	18.2	17.1
6 29 N 116 W	17.5	16.2	15.9	15.7	15.9	16.4	17.1	18.6	20.1	20.5	19.9	18.7	17.5
7 28 N 115 W	18.2	17.0	16.2	15.0	16.0	16.2	16.9	18.7	20.3	21.0	20.5	19.4	18.2
8 27 N 115 W	18.0	17.4	16.6	16.1	16.1	16.4	17.0	19.1	20.0	21.7	21.3	20.0	18.0
9 26 N 114 W	20.1	18.5	17.7	16.9	16.6	16.0	17.4	19.0	21.9	23.0	22.7	21.2	20.1
10 25 N 113 W	21.2	19.5	18.6	17.6	17.2	17.2	18.0	20.9	23.3	24.6	24.1	22.7	21.2
11 24 N 112 W	22.5	20.5	19.3	18.2	17.0	17.5	18.2	22.0	24.9	26.2	25.6	23.9	22.5
12 23 N 111 W	23.6	21.6	20.3	19.3	18.0	18.6	19.4	23.4	26.6	27.5	26.7	25.1	23.6
13 22 N 110 W	24.4	22.5	21.4	20.0	20.6	20.6	21.9	25.2	27.9	28.3	27.5	26.2	24.4
14 22 N 108 W	25.4	23.1	22.5	22.6	22.5	24.0	25.0	27.1	28.9	29.0	29.0	27.3	25.4
15 22 N 106 W	26.1	24.1	24.0	22.9	24.0	27.1	27.7	30.1	29.7	29.9	27.9	28.2	26.1

SEA SURFACE TEMPERATURE CONCEP - GULF CAL LONG TERM MEAN 1978-197

	1978 J	F	M	A	M	J	J	A	S	O	N	D	1979 J	F	M
1 34 N 120 W	2.0	-1.5	2.0	-.3	0.4	-1.6	-2.4	-.4	-.9	1.1	0.4	-.3	-1.2	-.4	-.9
2 33 N 119 W	1.0	0.7	-.1	-.7	-.6	-.9	-.1	0.2	1.3	-.8	-1.0	-1.2	-2.4	-.6	-.5
3 32 N 117 W	1.7	1.2	2.4	1.8	0.3	1.6	-.2	1.2	0.1	1.4	0.8	-1.2	-.2	-.4	0.3
4 31 N 117 W	1.3	1.3	0.6	1.1	0.7	0.4	0.5	0.2	-.0	0.1	-.4	0.0	-.2	-.4	0.1
5 30 N 116 W	1.0	0.4	0.7	1.2	1.0	1.0	-.2	0.1	-1.7	-.4	0.2	-1.4	-.3	-.6	0.1
6 29 N 116 W	1.7	1.2	1.8	0.5	0.9	0.9	0.5	-.2	-1.1	0.5	0.6	-.3	-.2	-.7	0.0
7 28 N 115 W	1.0	0.3	0.9	0.9	0.7	0.2	-1.7	0.5	-1.3	-.7	-.1	-1.7	-1.0	-.8	0.3
8 27 N 115 W	0.3	1.0	1.7	0.3	0.4	1.4	0.2	-.5	-1.5	0.4	0.4	-.4	-1.0	-1.4	-.1
9 26 N 114 W	1.9	0.4	1.2	1.1	0.8	0.2	0.1	-1.0	-2.0	0.1	-.0	-1.1	-1.0	-1.5	0.2
10 25 N 113 W	1.6	1.1	1.1	0.6	1.4	-1.0	-1.0	-.9	-2.8	-.4	-.4	-1.5	-1.0	-.8	-.2
11 24 N 112 W	1.2	0.5	1.7	0.4	0.9	1.0	1.0	0.6	-1.4	-1.0	-1.5	-1.2	-.5	-1.0	-.2
12 23 N 111 W	0.9	0.9	0.4	0.8	0.3	0.4	1.0	1.3	-.9	0.5	0.7	-1.9	-1.4	-1.2	0.1
13 22 N 110 W	1.7	1.5	0.6	-.0	0.1	0.5	-.4	0.4	-1.3	0.7	0.2	-1.7	-.7	-1.3	-.4
14 22 N 108 W	0.9	0.5	-.6	0.3	0.2	-1.2	0.9		0.7	0.6	1.8	-1.1	-1.3	-1.8	-1.4
15 22 N 106 W		0.0									-.5	-2.3		-2.0	-.6

Figure 16.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from Point Conception to the Gulf of California (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 28801.

and the opposite circulation, downwelling, occurred. Ekman transports at points off California (Fig. 2) were also weaker than long-term mean conditions during this period. Sea-surface temperatures were up to 2°C above normal during December-April. These conditions were associated with apparently stronger than normal transports by the northward flowing, near shore California Counter Current (Davidson Current).

The effects of increased northward transport by the California Counter Current on marine populations remain unclear. Parrish and Bakun (1979) suggested that the extremely low upwelling indices during early 1978, together with associated warmer than normal SST's, could have allowed anomalous northward migration of southern species along the coast. Commercial swordfish landings in 1978 in southern California were nearly double the previous record (set in 1978) and may have resulted from increased northward advection.

Anomalously strong northward advection along the coast, combined with above normal SST's, may also explain unusual recoveries of tagged billfish off southern California in October 1978.[18] Of the several thousand marlin tagged by the Southwest Fisheries Center, all those previously recovered had been taken to the south and southwest of San Diego, off Baja California and central Mexico, around the Hawaiian Islands, and near the Marquesas Islands in the southeast Pacific. None before had ever been recovered off southern California.

Other unusual occurrences of tropical species were reported in summer 1978. A triggerfish (a tropical reef fish) was caught near Monterey, CA, on September 20, 1978.[19] Radovich (1960) discussed anomalous catches of various species, including triggerfish, along the California coast during the unusual warm period in 1957 and 1958.

The onshore Ekman transport in early 1978 appeared to concentrate anchovy larvae near shore and allow improved reproductive success. Seckel et al. (1978) described the large-scale atmospheric circulation over the west coast during the period 1976-78 and the upwelling conditions that resulted from that circulation. They suggested that onshore Ekman transport during early 1978 (and the resulting weak upwelling indices) apparently concentrated anchovy larvae and their forage organisms near the California coast and resulted in good spawning success relative to the spawning stock size. In other years when onshore transport is less apparent, spawning success may be reduced by loss of larvae to offshore areas. Seckel et al. further suggested that the large numbers of young-of-the-year anchovy observed in southern California waters during spring and summer 1978 and unusually large concentrations of young fish as far north as Monterey Bay appear to support their hypothesis.

Salinity - Salinities along the California coast were below normal during 1978 and early 1979, particularly in the first quarter of each year. Data on temperature and salinity at the surface and bottom (about 5 m) at Scripps Pier in La Jolla, CA, are shown in Figure 16. The origin of the low-salinity water is unclear; it may be due to such processes as increased advection of low-salinity water from northern areas, above normal precipitation, or decreased upwelling of high-

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[18] News release, October 17, 1978, Southwest Fisheries Center, NMFS, La Jolla, CA 92038. Two record recoveries made of tagged billfish off southern California.

[19] Monterey Peninsula Herald, September 20, 1978.

salinity water from depth. Low-salinity water was also observed off southern California in 1978 during CalCOFI cruises,[20] and was noted up to 1,500 km offshore of central California in surface salinity observations made by merchant ships.[21]

The time series of salinity at Scripps Pier in 1978-79 looks remarkably similar to that observed during the period 1941-42 (Fig. 17). Note also the occurrence of above normal temperatures at Scripps Pier in the winters of 1976-77 and 1977-78, and the similar above normal temperatures in the winters of 1939-40 and 1940-41.

Eastern Tropical Pacific

An important process causing variations of oceanographic conditions in the Eastern Tropical Pacific (ETP) from one year to the next is the so-called El Niño. When this event occurs, sea levels and sea-surface temperatures are above normal in the waters off Ecuador and Peru, the normal upwelling of nutrient-rich deep waters into the surface waters is disturbed and biological productivity of the area is reduced. Wyrtki (1978) suggested that the El Niño conditions normally follow periods of strong trade winds which pile water up in the western tropical Pacific. As the trade winds relax, eastward flow increases in the Equatorial Counter Current towards South America, raising SST's and sea levels along the coast, depressing the thermocline, and reducing the normal upwelling of nutrient-rich water from depth.

Southern Oscillation - The variation of atmospheric pressure across the tropical Pacific, called the Southern Oscillation, has been correlated with recruitment of skipjack tunas (IATTC 1978, 1979). Quinn (1978, 1979) developed an index of the Southern Oscillation as the difference in surface atmospheric pressure between Easter Island in the eastern Pacific and Darwin, Australia, in the western Pacific:

$$\text{S.O. Index} = P_{\text{Easter}} - P_{\text{Darwin}}.$$

A time series of this index is shown in Figure 18 for the period January 1948-June 1979. During 1970-71 the index was positive for many months, indicating a strong pressure difference across the Pacific and strong trade winds. In 1972 the difference fell rapidly, the trade winds relaxed, and SST's (squares 308-1, 9-1, and 46-1 in Fig. 8) and sea levels (data for California stations shown in Fig. 6) increased as a major El Niño developed (Miller and Laurs 1975). In 1973 the pressure difference increased, sea levels and SST's returned to more normal values, and the El Niño condition disappeared. In 1975-76 a weaker cycle occurred with a positive pressure difference in 1975, a falling difference in 1976, and a weak El Niño response. The pressure difference has remained negative (near zero in mid-1978) since 1976 for an unusually long period of time. Thus the trade winds have been weak for the last three years and the probability of a major El Niño in 1979 and early 1980 is very low.

Temperature - Oceanographic conditions in the ETP are commonly monitored from patterns of SST and its anomaly from a long-term mean. Maps of anomaly of SST in the ETP are published monthly in Fishing Information. The following discussion is based on those maps, and the reader is referred to them and the accompanying descriptions for details

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[20] R. Lynn, Southwest Fisheries Center, NMFS, La Jolla, CA 92037. Personal communication.

[21] J. F. T. Saur, Scripps Institution of Oceanography, La Jolla, CA 92038. Personal communication.

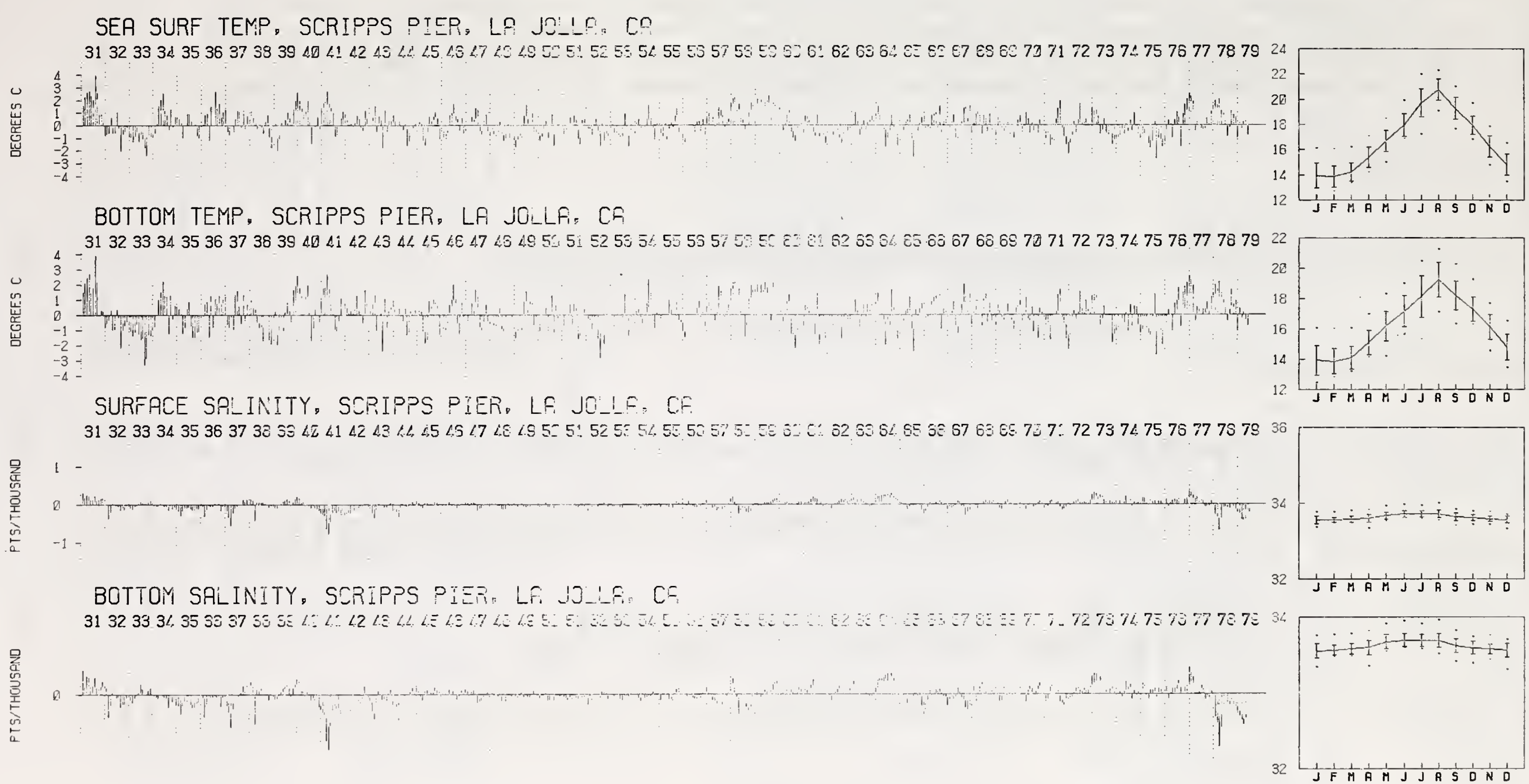

Figure 17.--Time series for 1931-79 of anomaly of temperature in degrees Celsius and salinity in parts per thousand at the surface and bottom (5 meters) at the end of Scripps Pier, La Jolla, CA, from the long-term mean reference period 1948-67. Data from C. Conway, Scripps Institution of Oceanography, La Jolla, CA 92038.

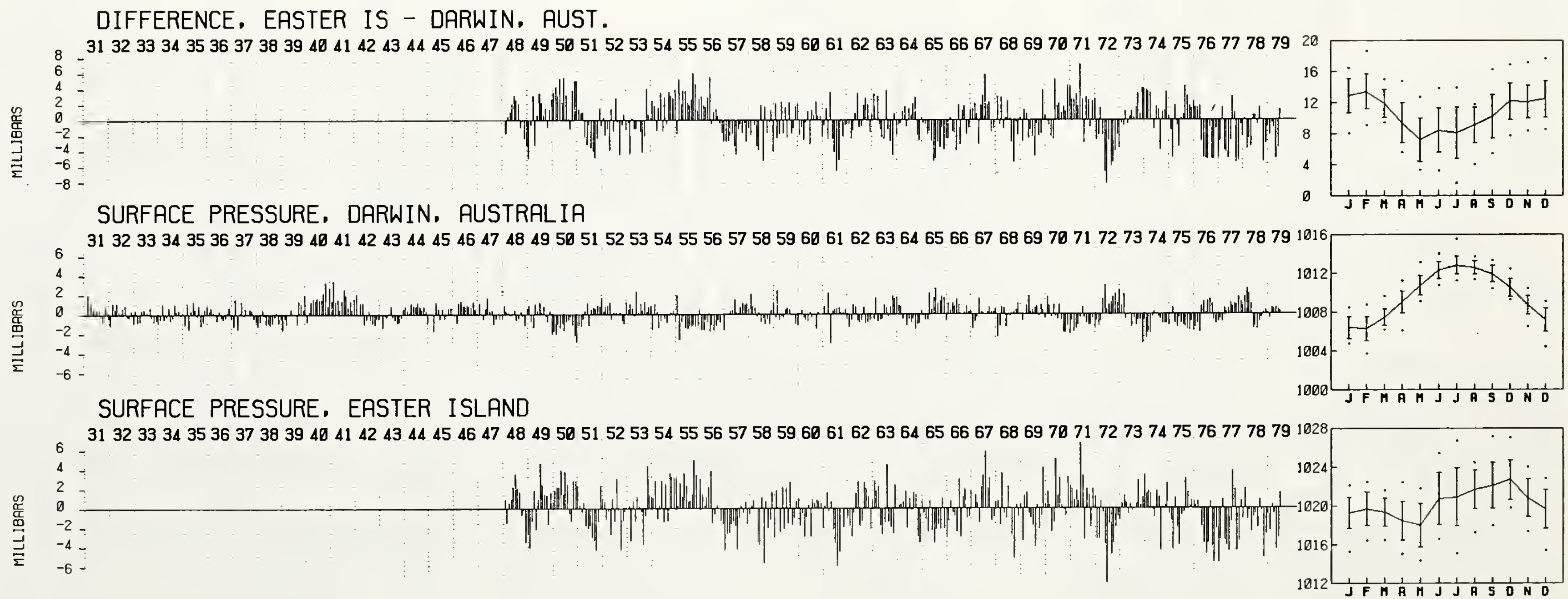

Figure 18.--Time series for 1931-79 of anomaly of surface atmospheric presure in millibars at Easter Island and Darwin, Australia, from the long-term mean reference period 1948-67. The difference between the two stations is an index of the Southern Oscillation. Developed by W. Quinn, Oregon State University, Corvallis, OR 97331.

of ocean conditions during 1978 and early 1979.

During January 1978 SST's were above normal over much of the ETP in the area west of 110°W due to weak trade winds and a relaxation of the subtropical high-pressure system off California. Upwelling off Peru and westward along the Equator caused below normal SST's east of 110°W as did strong wind mixing in the Gulfs of Tehuantepec and Panama and along the west coast of Nicaragua.

This general pattern persisted through February, but by March SST's had returned to near normal values over most of the area. Below normal SST's persisted in the Gulfs of Tehuantepec and Panama due to northerly winds blowing across Central America from the Gulf of Mexico.

In April the subtropical high-pressure system over the ETP continued weaker than normal. Lighter than normal winds and less than normal cloud cover resulted in above normal SST's in a large area southwest of Baja California. A dramatic increase in equatorial upwelling reduced SST's to below normal values in a broad band along the Equator from the coast of Peru to 180° and beyond.

Below normal SST's along the Equator continued as the dominant feature of the SST patterns from April through September. The colder than normal temperatures were typical of an "anti-El Niño" situation where the trade winds are moderately strong (note the positive pressure differences in mid-1978, Fig. 20) and upwelling of cold water along the Equator was intense.

The band of below normal SST's along the Equator broke up in fall, and by November SST's were near normal over the entire ETP, except for below normal SST regions along the equator near Equador, in the Gulf of Tehuantepec, and off Baja California. This general pattern of near normal SST's over the ETP with below normal SST pools near the coast persisted through March 1979.

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MARINE ENVIRONMENTAL CONDITIONS OFF THE ATLANTIC AND GULF COASTS OF THE UNITED STATES
January 1978 - March 1979

Merton C. Ingham[1] and Elizabeth D. Haynes[2]

LARGE-SCALE MARINE CLIMATIC CONDITIONS

Atmospheric Circulation

The upper level atmospheric circulation is an important index to climatological variations. The upper air (700 mb) circulation was characterized by a trough of low pressure near the U.S. east coast which persisted from the winter of 1977-78 until spring 1979, although it moderated somewhat during the warmer months. By August 1978, as a consequence of the filling of the low-pressure area, flow was more nearly zonal (westerly) north of 40°N, and a strong high-pressure system became established over the southeastern United States. In late fall a trough in the western United States produced southwesterly flow with warm temperatures for the east coast, which persisted until the end of the year. In January, the trough was reestablished over the east coast, producing cold northwesterly winds and record cold temperatures for the midwestern States, and wet, stormy weather for the eastern seaboard and nearby coastal waters. (See Fig. 1 on pages 6 and 7.) This condition began to moderate in the spring of 1979.

Wind-Driven Transport

A first approximation of the general effect of the wind field on ocean surface layer circulation can be obtained by computing monthly average Ekman transports at selected points in the area of interest. The NMFS Pacific Environmental Group, Monterey, CA 93940, routinely performs this computation for a large number of grid points, using a method described by Bakun (1973), utilizing mean monthly surface pressure data. Representations of these transport data for 1978 and early 1979 and for a 10-year mean period (1964-73) are shown in Figures 1 and 2.

In the waters off southern New England (40°N, 70°W) transport during 1978-early 1979 was generally similar to the 10-year mean. However, transports in February and December 1978 and February 1979 were unusually strong (Fig. 1). Off the middle Atlantic states (35°N, 75°W), transports were normal or low except for strong westward movement in February 1978 and northwestward instead of southwestward transport in November. In the South Atlantic Bight (30°N, 80°W), transports were all near normal except that in August, October, and November they were stronger than averages from the 10-year base. March 1978 and 1979 transports were virtually nonexistent. In the Gulf of Mexico, transport normally is much stronger than it is off the U.S.

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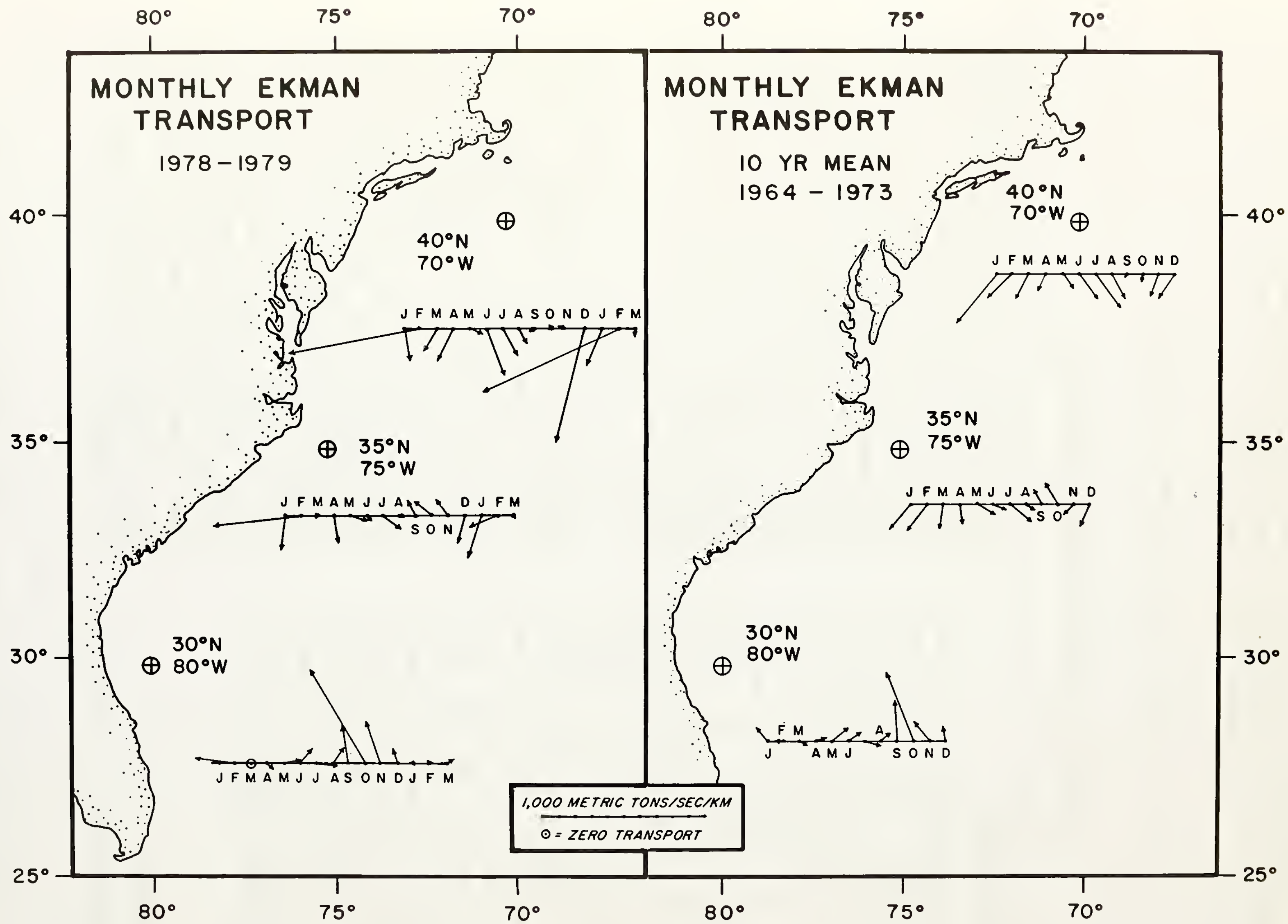

Figure 1.--Vectors of monthly mean Ekman transport for 15 months during January 1978-March 1979 (left) and the 10-year (1964-73) mean monthly values (right) for selected points along the Atlantic coast. Data were computed from mean monthly atmospheric pressure fields by the Pacific Environmental Group, NMFS, Monterey, CA 93940.

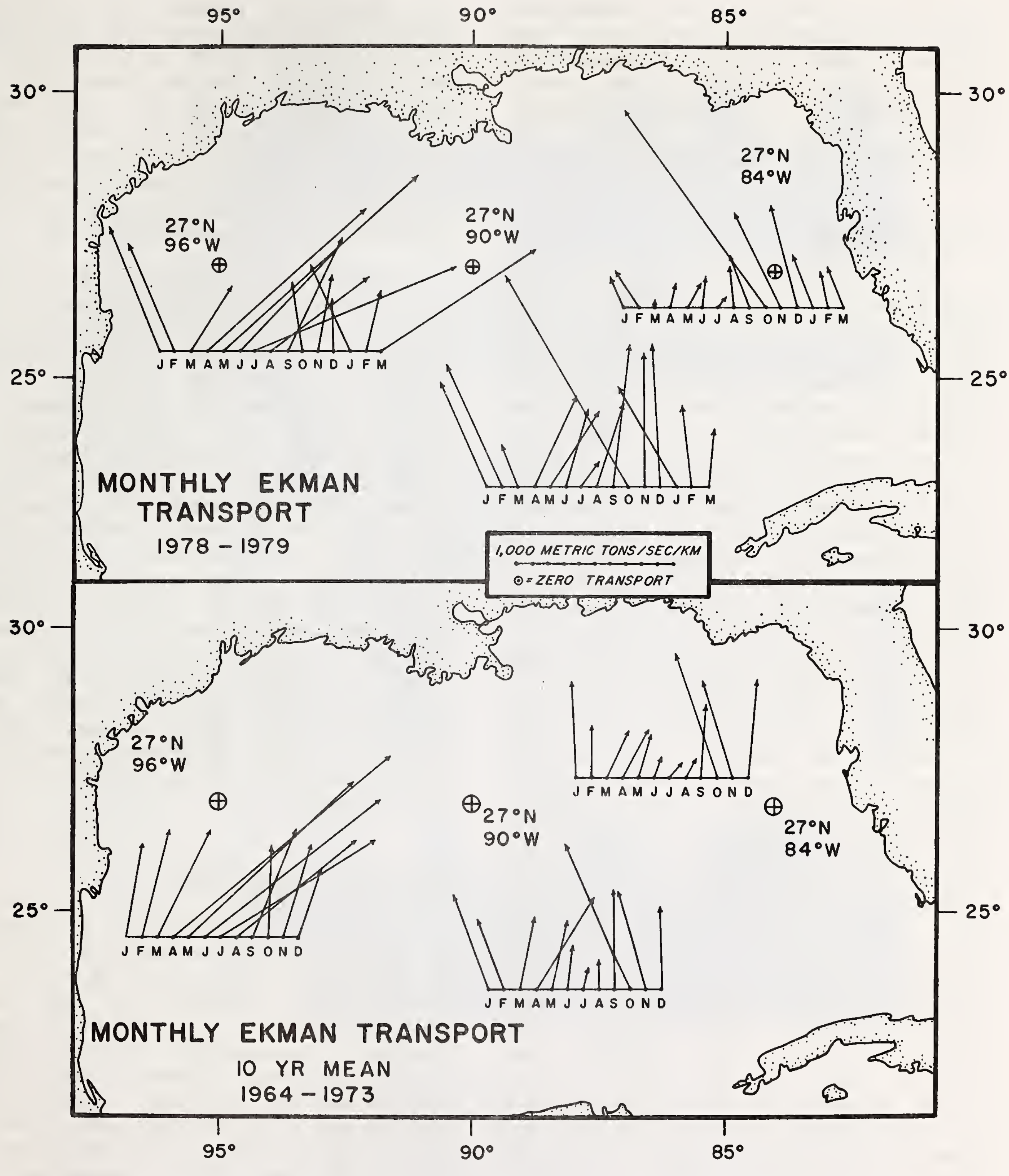

Figure 2.--Vectors of monthly mean Ekman transport for 15 months during January 1978-March 1979 (upper) and the 10-year (1964-73) mean monthly values (lower) for selected points in the Gulf of Mexico. Data were computed from mean monthly atmospheric pressure fields by the Pacific Environmental Group, NMFS, Monterey, CA 93940.

east coast (Fig. 2), and apparently large variations from the 10-year mean may be insignificant. Transport in October 1978 in the eastern and central Gulf approached twice average strength. In the western Gulf, transport was slightly stronger than average.

Air Temperature

Air temperature anomalies for coastal weather stations (Table 1) were rather patchy during the spring and summer of 1978, in striking contrast with the widespread pattern of colder than normal temperatures which occurred during January-March. By August most of the reporting stations, except in New England, were showing higher than normal temperatures due to the presence of a strong high pressure system over the southeastern States that transported warmer southern air northward. This temperature pattern became more intensive and extensive in the fall, with the strongest anomalies developing in the southeastern Atlantic States in November. By December the higher temperatures in the Gulf States began to return to normal, but the New England States began to show positive anomalies in December and were warmer than usual in January. Areas south of Cape Hatteras were much colder than normal in January due to the development of a pronounced 700 mb trough over the U.S. east coast which again advected very cold air on strong westerly winds. In February all stations were reporting unusually cold temperatures with the strongest anomalies in the middle Atlantic and southern New England States as the trough intensified and edged eastward over New England from the bitterly cold midwestern States, drawing the cold Canadian air to the coast. Norfolk, VA, showed an anomaly of $-8.1^{\circ}F$ in February, and all points to the north were more than $7.0^{\circ}F$ colder than the long-term mean. The air temperature at Block Island, 26 km off the Rhode Island coast, was $9.2^{\circ}F$ colder than normal. The situation changed rapidly in March, and the area coldest in February (Block Island) now showed the strongest positive anomaly instead.

Although the winter of 1978-79 was not as severe nor as long-lived in the Atlantic and Gulf coastal States as the preceding two winters, it was the third consecutive unusually cold one. This is the first time that three winters of such severity have occurred consecutively in the meteorological records of the United States.[3] The impact of cold weather would be particularly strong on marine organisms whose immature stages overwinter in estuarine or shallow water areas. For example, the high mortality of juvenile croaker in Chesapeake Bay which occurred in February 1979 was a result of the record cold period. However, survival may have been better than in the previous two winters (Wojcik 1978), because these unusually cold conditions were of shorter duration, not occurring in 1979 until February.

Sea Surface Temperature

Water temperature data, principally collected from cooling water intakes of merchant ships, are reported in radio weather messages and log books transmitted to the U.S. Navy Fleet Numerical Oceanography Center (FNOC) and the National Climatic Center for processing and archiving. The "real-time" reports of the data base provided by the radio messages are analyzed by FNOC and the Pacific Environmental

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[3]Diaz, H. F., and R. G. Quayle, 1979. An analysis of the recent extremes of winter temperature and precipitation in the contiguous United States. Unpublished report. National Climatic Center, NOAA, Asheville, NC 28801.

Table 1.--Monthly mean air temperature anomalies (^{o}F) for selected coastal weather stations for January 1978-March 1979. Dark shading indicated negative anomalies >2^{o}F, light shading indicates positive anomalies >2^{o}F.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Portland, ME	0.4	-3.7	-1.6	-2.1	0.0	-1.2	0.0	2.2	-0.9	-0.9	-2.2	0.4	2.2	-7.3	3.8
Boston, MA	-0.7	-3.3	-1.9	0.2	0.7	0.3	-1.2	0.3	-3.1	-2.9	-1.6	2.3	3.3	-7.3	4.4
Block Island, RI	-2.2	-4.9	-2.7	-1.4	-0.5	0.7	-1.6	1.8	-2.5	-1.2	0.4	2.8	1.7	-9.2	3.1
New York, NY	-2.2	-5.4	-0.6	0.7	-0.3	1.2	-0.6	3.9	-0.4	0.0	2.3	4.4	1.8	-7.2	6.1
Atlantic City, NJ	-3.6	-7.5	-1.6	-0.9	-4.3	-3.2	-3.7	0.7	-3.2	-3.7	-0.2	1.6	-1.7	-7.7	1.9
Norfolk, VA	-3.5	-8.8	-2.0	-0.6	-1.1	-0.4	-2.2	3.6	1.4	-0.9	4.4	3.0	-1.1	-8.1	1.0
Cape Hatteras, NC	-3.3	-10.1	-0.5	1.3	-1.9	0.5	0.0	3.1	2.6	-1.7	5 3	3.5	0.1	-4.8	0.1
Charleston, SC	-5.1	-7.8	-1.3	1.9	-0.1	0.7	0.9	1.7	2.2	-0.4	7.0	3.4	-3.2	-3.7	0.9
Savannah, GA	-6.0	-8.5	-1.7	1.9	0.4	0.9	1.1	1.7	2.0	-0.1	7.6	3.0	-4.5	-3.1	1.8
Jacksonville, FL	-6.0	-8.8	-2.5	0.2	0.5	0.3	0.8	-0.2	-0.4	-2.7	3.4	-0.3	-6.7	-4.3	-0.4
Miami, FL	-3.2	-4.6	-2.4	-1.0	1.2	0.9	0.2	-0.3	0.3	1.0	3.5	4.7	-2.2	-2.9	-2.1
Tampa, FL	-5.4	-8.6	-1.8	0.3	1.5	1.4	1.1	0.6	0.6	0.4	4.9	4.6	-2.6	-2.5	-0.6
Apalachicola, FL	-8.1	-8.9	-4.4	-1.9	-1.0	-0.7	-0.6	-0.6	0.5	-2.2	4.5	1.1	-5.8	-5.1	-2.3
Mobile, AL	-10.0	-8.9	-2.7	0.6	0.6	0.9	1.2	1.7	4.1	0.9	6.6	1.5	-6.1	-3.3	1.4
Lake Charles, LA	-9.4	-9.5	-2.5	-0.7	1.6	0.1	0.5	-0.4	0.0	-1.3	4.2	-0.8	-7.9	-4.8	0.7
Galveston, TX	-8.6	-9.2	-2.7	-0.8	0.8	1.3	0.7	1.2	1.4	0.3	3.2	0.3	-6.9	-4.3	0.6
Corpus Christi, TX	-7.1	-7.9	-1.0	-0.5	3.1	1.1	0.8	-0.2	0.9	-0.7	3.9	0.0	-5.0	-2.6	3.0
Brownsville, TX	-5.7	-7.5	-0.9	-0.1	4.0	2.2	2.4	1.0	0.7	0.2	3.1	0.1	-4.0	-3.9	1.3

Group of the National Marine Fisheries Service, which is colocated with FNOC. These data are plotted by $1^{o} \times 1^{o}$ squares (where sufficient data are available) as the anomaly from the computed mean monthly temperatures from the 1948-67 means. (See Appendix.) Within each square the average temperature for the month appears at the top, the anomaly in bold type in the middle, and the number of observations at the bottom. To facilitate interpretation of the data, anomalies greater than $+1^{o}$C or 1^{o}C are shaded.

The anomaly maps revealed that in the northwestern Atlantic (35^{o}-46^{o}N, west of 60^{o}W) in 1978 sea-surface temperatures (SST) generally were cooler than the long-term mean in the first half of the year. Extensive areas of negative anomalies as great as -7.7^{o}C (off Cape Hatteras) developed, with the most extensive and intensive occurring in February. The anomalies generally were stronger in the southwest corner of the area, but the cold water extended farthest eastward off the Middle Atlantic Bight and southern New England (38^{o}-41^{o}N). Warm anomaly areas appeared in August, November, and December. In January-March 1979 a very similar pattern of negative anomalies developed, as extensive in area, but not quite as strong in magnitude.

In an effort to characterize the monthly sea-surface temperature conditions for the entire northwestern Atlantic area with a single number, the mean of all the mapped anomalies was computed for each month. The resulting monthly area means (Table 2) showed negative values for all months except August, November, and December. However, the magnitudes of the anomalies were significantly less than the standard deviations for the reference period (1948-67). Apparently the negative anomalies in 1978 and early 1979 were not unusually intense, even though they were widespread and persistent. It is interesting to note that the strongest negative anomalies occurred in February in both years, but the March values were considerably different, with March 1979 being warmer. The same pattern was seen in the air temperature records from the coastal weather stations discussed earlier.

Table 2.--Monthly mean sea-surface temperature anomalies (^{o}C) from the 1948-67 monthly means for 1978 in the northwestern Atlantic Ocean (35^{o}-46^{o}N, 60^{o}-76^{o}W).

Month	Number of 1^{o} squares	Area mean anomaly	Standard deviation of area mean anomaly during 1948-67
Jan 1978	101	-0.29	1.26
Feb	120	-0.80	1.23
Mar	115	-0.75	1.49
Apr	125	-0.47	1.51
May	126	-0.45	1.22
Jun	129	-0.03	0.91
Jul	119	-0.38	0.89
Aug	117	+0.36	0.85
Sep	109	-0.03	0.89
Oct	117	-0.44	0.95
Nov	112	+0.07	0.90
Dec	112	+0.29	0.91
Jan 1979	117	-0.18	1.26
Feb	109	-0.80	1.23
Mar	121	-0.35	1.49

REGIONAL CONDITIONS

Gulf of Maine

Sea-Surface Temperature - In the Gulf of Maine, systematic records of SST's are available from daily observations at Boothbay Harbor, ME, and monthly expendable bathythermograph (XBT) transects by ships of opportunity operating between Portland, ME, and Yarmouth, NS, and between Gloucester, MA, and Cape Sable, N.S. (Fig. 3).

Monthly average SST's from the Boothbay Harbor records (Table 3) clearly showed the influence of two unusually cold winters and the warm, high-pressure weather system in August. Comparison of the departures from the 20-year means with the standard deviations for the data record means reveals that they exceeded the standard deviations in only three months: February, April, and December 1978.

Figure 3.--Ship-of-opportunity transect locations in the Gulf of Maine.

Table 3.--Boothbay Harbor, ME:

(A) Monthly average sea surface temperature (^{o}C),
(B) differences from the 20-year (1948-67) mean, and
(C) standard deviations of observations about the mean.

1978	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(A)	2.6	0.8	2.0	4.0	8.0	11.0	14.8	16.1	10.8	7.9	4.0	3.1
(B)	-1.0	-1.7	-1.1	-1.4	-1.1	-1.0	-0.6	+0.3	-1.0	-0.5	-0.9	+2.0
(C)	1.3	1.5	1.3	1.2	1.3	1.1	1.2	0.9	1.1	1.3	1.3	1.4

1979	Jan	Feb	Mar	Apr
(A)	3.1	1.0	2.2	4.7
(B)	-0.5	-1.5	-0.9	-0.7
(C)	1.3	1.5	1.3	1.2

Source: Maine Department of Marine Resources
Division of Marine Research
West Boothbay Harbor, ME 04575

The SST's observed on the Portland, ME, to Yarmouth, N.S., transects in 1978 and early 1979 (Table 4) reflected the same patterns shown by the Boothbay Harbor data: an unusually warm August occurring between two unusually cold winters.

During February-March 1979 the surface temperatures fell to their annual minimum, with values quite similar to those of 1978. However, February 1979 was a bit warmer (about half a degree) and March was a bit cooler (also about half a degree).

Contrary to conditions farther south in the Middle Atlantic Bight, spring temperatures in the western Gulf of Maine were warmer in 1978 than in 1976 and 1977. This probably was the result of heavier rainfall and river discharge in March and April of 1978.

Water Column Thermal Structure - Vertical profiles of temperature are routinely plotted from XBT data taken by the two ships of opportunity mentioned above (Fig. 3). These observations are made at hourly intervals during the monthly passages. A description of water column temperature structure in 1978 was prepared by Kirschner[4] based on these transects.

Seasonal warming began in surface waters in April 1978 from the year's observed minima of 0.6^{o}C along the eastern shore and <3^{o}C in the central Gulf. The minimum bottom temperature at this time was located near the deepest basin. Bottom temperatures cooled slowly as spring advanced, but remained >7^{o}C for two months while the surface waters warmed to nearly 10^{o}C off Portland in May. An intermediate layer of water <5^{o}C remained at 50-100 m

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[4]Kirschner, R. Temperature structure and surface salinity in the Gulf of Maine during 1978. Unpublished report. Northeast Fisheries Center, NMFS, Woods Hole, MA 02543.

Table 4.--Sea-surface temperature (^{o}C) at XBT drop points on the Portland-Yarmouth transect in the northern Gulf of Maine

	Portland, ME										Yarmouth, NS
Station	11	10	9	8	7	6	5	4	3	2	1
<u>1978</u>											
19 Jan	2.8	3.7	4.4	4.8	4.2	3.8	4.4	4.3	4.2	3.8	3.1
19 Feb	1.0	3.0	3.2	3.0	2.6	2.5	3.0	2.1	2.6	2.6	0.7
16 Mar	2.0	2.3	2.9	2.6	2.6	2.6	2.7	4.1	3.6	2.6	0.6
25 Apr	5.3	4.9	4.7	4.8	4.4	5.2	5.3	-	4.4	3.9	3.3
23 May	-	9.8	7.8	6.5	6.1	7.6	7.9	7.1	6.7	5.2	5.5
22 Jun	13.2	12.1	11.7	11.1	8.2	10.3	11.5	12.1	11.5	10.7	7.3
25 Jul	14.9	15.4	14.2	13.3	13.4	14.7	15.7	14.0	12.0	9.9	9.5
15 Aug	17.4	18.3	19.5	14.9	15.2	16.3	17.6	17.6	16.7	13.2	10.8
17 Sep	12.1	12.5	11.7	11.4	11.1	12.1	12.9	13.0	12.0	10.9	11.5
17 Oct	10.4	10.4	10.3	9.9	10.9	10.3	10.8	10.7	10.8	11.1	11.5
23 Nov	8.2	8.8	9.1	8.9	8.8	8.9	8.9	9.1	8.9	-	8.8
21 Dec	6.8	6.4	6.3	7.1	7.2	7.2	7.2	7.1	7.2	7.1	6.3
<u>1979</u>											
January - No Data											
20 Feb	0.0	1.5	2.7	3.9	4.6	3.7	4.5	3.5	3.2	2.7	2.9
18 Mar	1.5	2.0	2.5	2.9	2.5	2.5	1.9	2.2	1.7	1.7	1.3
12 Apr	3.9	4.0	3.4	3.2	3.5	3.6	3.6	3.9	4.0	3.9	3.0

depth. A strong thermocline developed in the western Gulf at about 50 m by early June, and surface temperatures reached 13.2°C off Portland. This warming extended into the intermediate layer, though not to the bottom water.

The thermocline strengthened above 30 m during the summer, and the surface temperature reached a high of 22.2°C over Cashes Ledge on the Gloucester-Cape Sable transect in August. Beneath the thermocline, the intermediate band of cool water disappeared by July and bottom temperatures continued at about 6.5°C.

In September the thermocline began to break down, with the surface waters being mixed downward. Surface cooling and mixing continued until a nearly isothermal condition was reached in December. Shore to shore and surface to bottom the temperature varied by only about 1.5°C, between 6.3°C and 7.8°C, with the shallower coastal water being cooler. This development was quite similar to the pattern of 1977, but comparison with vertical sections of temperature for the fall months of 1975, 1976, and 1977 (Kirschner 1979) showed that fall 1978 water column temperatures were significantly cooler. This condition apparently was the consequence of cooler (about 2°C) air temperatures and relatively little advection of warm Slope Water into the Gulf.

Cold air temperatures and strong winds caused considerable cooling in the Gulf during early 1979. In late January surface water temperatures ranged from about 5.3°C to 7.4°C. By late February these temperatures had fallen to 0.0°C near Portland, 2.9°C near Yarmouth, and 3.7°C in mid-transect. Bottom temperatures at this same time ranged up to 8.3°C in the deepest portion transited (about 220 m).

As summarized by Kirschner (see footnote 4), the subsurface thermal structure in the Gulf of Maine in 1978 was not highly unusual, except for its being slightly cooler and there being relatively few Slope Water (warm, salty) intrusions at mid-depths. Such intrusions were detected only in March and November on the Portland-Yarmouth line and in July, September, and October on the Gloucester-Cape Sable line.

Georges Bank

Sea-Surface Temperature - Considering just the Georges Bank subarea (40°-42°N, 66°-70°W), the anomaly maps (see Appendix) showed that the surface waters were cooler than the long-term monthly means throughout 1978 and the first three months of 1979. Pooled average monthly anomalies for the area (derived from 4,507 observations, Table 5) ranged from -2.0°C in May to -0.3°C in June 1978. The pattern of SST anomalies on the Bank was somewhat different from the pattern for the entire northwestern Atlantic. The Georges Bank negative anomalies were greatest in March-May, instead of February-March, and least in June instead of August. However, the patterns agreed well in November and December, when both areas showed very weakly negative (or positive) anomalies.

In the first three months of 1979 the SST's were cooler than normal, but not as cool as in 1978. Comparing the anomalies for 1976, 1977, 1978, and early 1979 (Table 5) shows a progression from warmer conditions in 1976 to cooler in 1978 with a slight warming occurring in early 1979.

Eddies - One of the principal mechanisms producing anomalous conditions in the water mass over Georges Bank is the passage of warm core Gulf Stream eddies along its outer edges. Eddy passages, summarized by Celone and Chamberlin[5] and updated for early 1979 by Celone,[6] showed an absence of eddies during January-March 1978, then an active 8-month period, during which six eddies were adjacent to some portion of the Bank, usually singly or occasion-

ally in pairs (Table 6). There were no eddies found adjacent to the Bank in the first three months of 1979. Perhaps as a consequence of this absence of eddies, the Shelf Water/Slope Water front, which normally is found near the edge of the Bank, appeared to move much farther seaward than usual, in places reaching the edge of the Gulf Stream about 150 km from the Bank in the early months of both years.

Table 5.--Monthly sea-surface temperature anomalies (°C) for Georges Bank (40°-42°N, 66°-70°W) from ship injection temperatures

Month	1976	1977	1978	1979
Jan	0.2	-0.9	-1.0	-0.8
Feb	0.3	-1.0	-1.4	-0.8
Mar	0.9	0.2	-1.6	-0.8
Apr	0.1	0.9	-1.3	
May	0.2	-0.2	-2.0	
Jun	1.4	-0.8	-0.3	
Jul	0.4	-0.7	-0.6	
Aug	0.0	-0.7	-0.6	
Sep	0.6	-0.2	-1.5	
Oct	0.8	-0.4	-1.2	
Nov	-1.0	-0.4	-0.4	
Dec	0.0	-0.9	-0.5	

The period during which eddies were found near Georges Bank in 1978 included the peak spawning periods (Colton et al. 1979) for several species in that area, including Atlantic herring, cusk, fourbeard rockling, haddock, silver hake, red hake, cunner, Atlantic mackerel, butterfish, and several flatfish. The quantities of eggs or larvae lost along with Shelf Waters pulled off the Bank by eddies are unknown, but they could be considerable.

Shelf Water/Slope Water Front - Both 1978 and 1979 apparently have shown major seaward excursions of the Shelf Water/Slope Water front during periods of eddy absence. According to a summary of frontal positions in 1978 prepared by Hilland and Armstrong,[7] a major seaward excursion of the front was seen throughout the Georges Bank-Cape Hatteras area during March-May,

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[5] Celone, P. J., and J. L. Chamberlin. Anticyclonic warm core Gulf Stream eddies off the northeastern United States during 1978. Unpublished report. Atlantic Environmental Group, NMFS, Narragansett, RI 02882.

[6] Celone, P. J. Atlantic Environmental Group, NMFS, Narraganansett, RI 02882. Personal communication.

[7] Hilland, J. E., and R. S. Armstrong. Variation in the Shelf Water front position in 1978 from Georges Bank to Cape Romain. Unpublished manuscript. Atlantic Environmental Group, NMFS, Narragansett, RI 02882.

which lasted until July in portions of the area. This occurrence apparently was accompanied by an invasion of the Slope Water area by cooler Shelf Water from the western Scotian Shelf past Georges Bank into the Middle Atlantic Bight (Chamberlin 1978).

Table 6.--Eddy formation and destruction dates and life spans. Dates in parentheses could be off by greater than one week. Dates not in parentheses are accurate to within one week, and generally are accurate to within several days

Eddy	Dates	Life span (Days)
77-D	(3/29/77) - 2/17/78	355
77-I	7/16/77 - 2/12/78	211
78-A	4/21/78 - 10/19/78	181
78-B	4/21/78 - 5/17/78	28
78-C	5/20/78 - 5/31/78	11
78-D	6/12/78 - 12/28/78	199
78-E	6/15/78 - 9/6/78	83
78-F	6/17/78 - 9/6/78	81
78-G	7/11/78 - 8/23/78	41
78-H	(10/10/78) - (11/8/78)	29
78-I	10/25/78 - into April 1979	>182
79-A	(3/1/79) - into April 1979	>31

Middle Atlantic Bight

Sea-Surface Temperature - In order to characterize the spatial and temporal gradients during the course of the year (1978) in Shelf Waters, the monthly anomalies from 15 coastal one-degree squares were plotted on a space-time grid (Fig. 4). The plot clearly shows that the Shelf Water exhibited the greatest negative anomalies in the late winter and spring months (February-May) and in the area off the Delaware Bay-Cape Hatteras (squares 12-15). In the New York Bight, however (squares 9-11), the negative anomalies were smaller and developed later in the year. Off southern New England (squares 6-8) the negative anomalies developed early in the winter, but were smaller in general than those in the southern squares. On Georges Bank (squares 4 and 5), development of negative anomalies was weak and sporadic. The Scotian Shelf (squares 1-3) showed no strong anomaly patterns, neither negative nor positive.

In 1977 (Fig. 5, left), by comparison, negative anomalies in Shelf Waters appeared earlier, being widespread in January (and December 1976). However, they weakened earlier, and by May only two squares showed values stronger than $-1^{\circ}C$. By June strong positive anomalies had developed off New Jersey to Virginia (squares 11-13). Geographically, the pattern in 1977 was somewhat similar to that in 1978, with the negative anomalies extending from

		1978											1979		
	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1 43 N 64 W	0.2 (6)	-.5 (7)	-.5 (9)	-.2 (15)	1.1 (17)	-.7 (16)	0.5 (4)	1.0 (1)	1.6 (12)	1.7 (12)	1.0 (8)	1.2 (6)	0.5 (20)	0.2 (7)	-1.1 (13)	-.5 (17)
2 43 N 65 W	-1.0 (8)	-.5 (5)	-1.0 (19)	0.7 (20)	1.2 (16)	0.3 (7)	0.1 (8)	-.7 (2)	-.8 (17)	1.0 (2)	1.6 (6)	1.1 (9)	-.9 (12)	-1.6 (11)	-.4 (6)	1.3 (16)
3 43 N 66 W	-.8 (7)	0.2 (2)	-2.0 (14)	0.6 (12)	0.6 (17)	0.2 (10)	-.6 (7)	1.6 (15)	1.1 (9)	-.7 (2)	0.3 (7)	0.8 (9)	-.2 (4)	-.3 (7)	-1.3 (8)	-.1 (6)
4 42 N 67 W	1.2 (3)	-1.0 (2)	1.6 (2)	-.6 (13)	-1.4 (2)	0.6 (17)	0.6 (15)	0.1 (6)	-.7 (10)	-.2 (14)	1.1 (35)	0.5 (12)	0.1 (3)	0.9 (4)	-.3 (4)	1.3 (3)
5 41 N 68 W	-.3 (8)	-.2 (2)	-1.7 (1)	-1.3 (31)	-.5 (4)	-.6 (13)	2.4 (3)	-1.0 (5)	-1.7 (8)	1.1 (4)	-1.0 (20)	0.5 (20)	-2.2 (6)	0.5 (1)	-1.0 (12)	-.6 (6)
6 40 N 69 W	-1.3 (207)	-1.1 (125)	-.7 (142)	-.7 (171)	-.7 (189)	-1.3 (221)	-2.3 (163)	-.6 (171)	1.2 (151)	-2.1 (131)	-1.0 (155)	-.5 (144)	-.9 (154)	-2.4 (170)	-1.2 (157)	-1.4 (229)
7 40 N 70 W	0.1 (9)	-.2 (20)	-1.4 (21)	-1.4 (34)	-2.3 (15)	-1.6 (17)	-.5 (7)	-.8 (17)	1.8 (10)	-1.6 (10)	-1.1 (22)	0.9 (9)	1.4 (4)	0.8 (10)	-1.2 (18)	-2.2 (19)
8 40 N 71 W	0.2 (9)	-.8 (8)	-.6 (15)	-1.9 (22)	-2.3 (25)	-2.0 (28)	-.7 (7)	-4.0 (10)	0.7 (21)	0.1 (15)	-1.7 (17)	-.2 (6)	0.6 (4)	0.6 (7)	-1.0 (7)	-1.5 (22)
9 40 N 72 W	-1.5 (6)	0.0 (1)	-.4 (3)	-2.7 (10)	-1.4 (15)	-1.9 (10)	-.2 (8)	-.7 (9)	1.2 (4)	1.6 (8)	-.8 (12)	0.7 (7)	0.2 (8)	0.5 (9)	-1.3 (5)	-.6 (19)
10 40 N 73 W	0.7 (191)	0.7 (134)	1.2 (26)	-.8 (16)	-1.0 (148)	-3.0 (154)	-1.0 (150)	-1.5 (134)	1.5 (131)	1.0 (42)	0.1 (13)	0.1 (49)	1.2 (174)	0.2 (2)	-.3 (120)	-.6 (172)
11 39 N 73 W	-.5 (16)	-.4 (18)	-1.7 (9)	-1.1 (14)	-1.9 (11)	-1.1 (15)	-.7 (19)	-1.4 (20)	1.2 (14)	1.3 (14)	-.5 (11)	0.7 (12)	0.7 (12)	0.6 (11)	-.4 (10)	-.9 (26)
12 38 N 74 W	-.8 (29)	-5.1 (8)	-2.6 (16)	-1.0 (29)	-2.0 (22)	-.6 (14)	-2.0 (26)	-.4 (26)	0.0 (7)	-1.3 (7)	0.2 (11)	-.4 (9)	1.6 (23)	-1.6 (17)	-2.2 (15)	0.4 (12)
13 37 N 74 W	1.1 (26)	-.5 (11)	-2.7 (23)	0.8 (44)	-1.7 (27)	-2.3 (15)	-1.4 (26)	0.3 (23)	0.9 (13)	2.3 (20)	-.3 (21)	-.4 (19)	1.4 (26)	-.6 (19)	-1.1 (18)	-2.1 (28)
14 36 N 75 W	-.8 (14)	-4.2 (13)	-4.0 (31)	-2.0 (30)	0.3 (30)	-2.0 (34)	-2.4 (20)	-.9 (14)	-.7 (2)	1.0 (11)	-.6 (16)	-.1 (14)		-.1 (10)	-3.0 (17)	-2.6 (24)
15 35 N 75 W	0.1 (10)	1.0 (19)	-7.7 (19)	-5.7 (10)	-4.5 (24)	0.7 (10)	0.8 (6)	1.7 (14)	1.0 (13)	1.6 (16)	-.9 (16)	-2.0 (10)	4.1 (18)	0.6 (16)	-5.5 (10)	-1.0 (22)

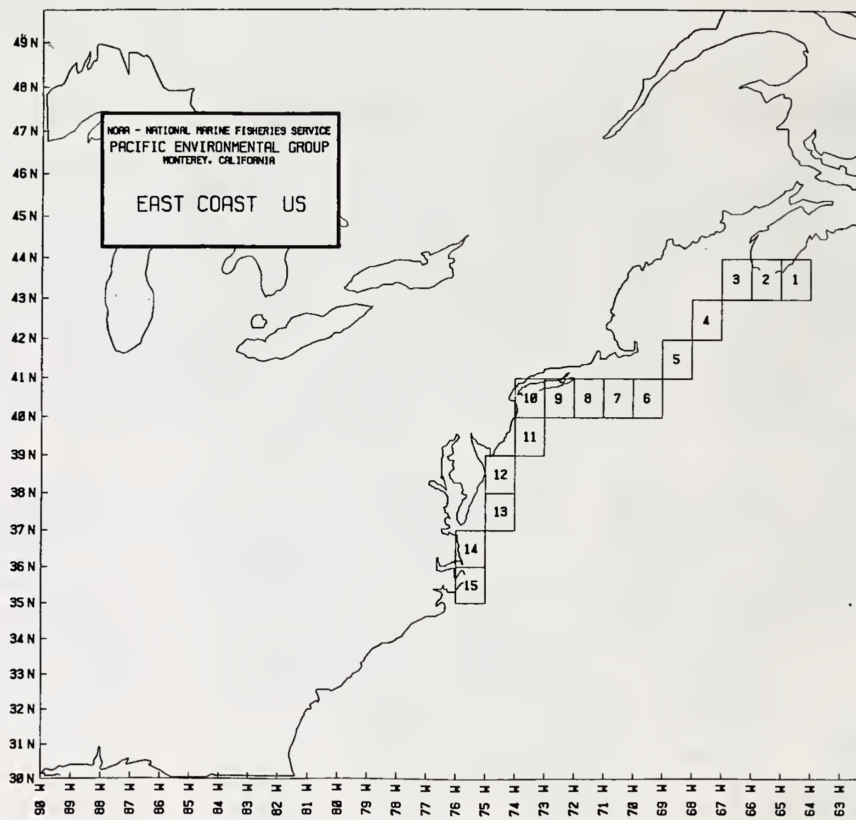

Figure 4.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (left) in degrees Celsius from the long-term mean reference period 1948-67 for fifteen 1-degree squares along the coast from Nova Scotia to Cape Hatteras (locations shown at right). Small numbers in lower left corner of matrix squares indicate the number of observations utilized.

1977

Square	D	J	F	M	A	M	J	J	A	S	O	N	D
1 43 N 64 W	-1.0 (4)	-2.8 (17)	-.0 (4)	0.6 (9)	-.2 (15)	-.5 (13)	0.1 (6)	1.2 (6)	-2.2 (9)	0.4 (4)	1.1 (18)	0.4 (5)	0.2 (6)
2 43 N 65 W	-1.0 (4)	-2.0 (5)	-.7 (3)	0.6 (13)	0.1 (8)	-.7 (9)	0.9 (5)	-.1 (9)	-.1 (8)	0.5 (5)	0.3 (11)	-.6 (5)	-1.0 (8)
3 43 N 66 W	-1.2 (2)	0.5 (4)	0.6 (2)	-.3 (4)	0.3 (3)	-1.5 (4)	-.3 (8)	0.5 (7)	0.0 (10)	1.1 (4)	1.4 (13)	1.2 (10)	-.8 (7)
4 42 N 67 W	0.3 (5)	0.1 (3)		0.5 (3)	-1.0 (3)	1.1 (5)	2.3 (7)	-1.2 (1)	0.4 (7)	-.7 (9)	-.1 (9)	-.2 (12)	1.2 (3)
5 41 N 68 W	-.1 (5)	-.7 (2)	1.7 (1)	0.5 (5)	0.3 (7)	-.1 (7)	-.0 (15)	-1.8 (12)	0.6 (31)	0.7 (38)	-1.8 (21)	-.4 (16)	-.3 (8)
6 40 N 69 W	-2.0 (159)	-2.8 (97)	-2.8 (139)	-.6 (172)	-.5 (192)	-.9 (196)	-2.3 (232)	-4.2 (156)	-2.7 (172)	-1.0 (208)	-1.2 (236)	0.2 (166)	-1.3 (207)
7 40 N 70 W	-1.5 (16)	-2.0 (26)	-1.8 (50)	-1.5 (28)	-2.3 (11)	0.4 (16)	0.1 (20)	-2.5 (7)	0.6 (6)	-.5 (18)	-.2 (12)	0.1 (15)	0.1 (9)
8 40 N 71 W	-1.2 (21)	-1.4 (32)	-1.0 (60)	-.9 (41)	-2.2 (7)	-.3 (7)	0.6 (13)	0.5 (10)	-.5 (12)	0.1 (15)	-1.4 (8)	-.4 (15)	0.2 (9)
9 40 N 72 W	-1.8 (13)	-1.4 (39)	-1.8 (10)	0.1 (19)	-1.5 (5)	0.4 (5)	-1.6 (9)	0.3 (10)	-.7 (5)	-1.3 (6)	-.5 (10)	-.9 (2)	-1.5 (6)
10 40 N 73 W	-.7 (54)	0.3 (8)	-3.0 (8)	-1.6 (14)	-1.8 (204)	-.7 (186)	-.1 (202)	0.1 (154)	0.7 (186)	1.2 (120)	-2.6 (36)	0.3 (191)	0.7 (191)
11 39 N 73 W	-1.9 (15)	-.3 (10)	-2.7 (7)	-1.4 (12)	0.0 (14)	0.6 (4)	1.2 (15)	-.5 (11)	-.4 (16)	0.6 (22)	-2.7 (16)	0.6 (17)	-.5 (16)
12 38 N 74 W	-1.9 (34)	-1.7 (12)	0.4 (18)	-1.4 (14)	-.3 (8)	3.7 (16)	2.2 (21)	0.6 (11)	0.9 (23)	0.9 (16)	0.2 (14)	-1.4 (24)	-.8 (29)
13 37 N 74 W	-.2 (29)	0.5 (31)	1.2 (28)	0.2 (53)	1.6 (28)	1.6 (57)	1.1 (32)	1.7 (27)	-.6 (30)	1.3 (45)	-1.8 (33)	-2.4 (34)	1.1 (26)
14 36 N 75 W	-1.7 (27)	-2.5 (40)	-4.0 (10)	-1.2 (19)	3.0 (8)	-1.1 (25)	-.4 (25)	1.1 (20)	-.9 (29)	1.4 (28)	-2.5 (16)	-1.8 (18)	-.8 (14)
15 35 N 75 W	-1.0 (18)	2.5 (9)	0.8 (8)	3.3 (16)	-.1 (15)	2.0 (16)	-.5 (16)	1.2 (10)	0.2 (13)	0.9 (24)	-.4 (21)	0.5 (13)	0.1 (10)

1976

Square	D	J	F	M	A	M	J	J	A	S	O	N	D
1 43 N 64 W	0.8 (9)	-.7 (9)	0.9 (12)	1.1 (14)	1.0 (15)	1.5 (5)	1.8 (13)	1.7 (10)	1.5 (15)	1.8 (7)	2.7 (7)	-2.7 (25)	-1.8 (4)
2 43 N 65 W	0.2 (9)	-1.4 (3)	-.0 (1)	0.6 (8)	1.2 (5)	1.0 (2)	1.4 (5)	1.8 (12)	0.9 (9)	-.5 (5)	2.0 (5)	-3.4 (29)	-1.0 (4)
3 43 N 66 W	0.2 (5)	1.0 (5)		2.3 (1)	2.4 (2)	1.4 (10)	2.3 (22)	3.9 (10)		0.3 (5)	0.6 (3)	-.2 (5)	-1.2 (2)
4 42 N 67 W	-.0 (2)	-.2 (3)	-.1 (4)	1.1 (7)	1.2 (8)	0.6 (14)	0.9 (6)	1.1 (5)	0.7 (8)	1.5 (5)	2.8 (1)	-.3 (12)	0.3 (5)
5 41 N 68 W	-.2 (16)	1.0 (1)	-.9 (5)	0.7 (13)	0.9 (9)	1.5 (10)	2.6 (12)	-.1 (10)	0.5 (24)	1.8 (81)	1.4 (19)	-.9 (20)	-.1 (5)
6 40 N 69 W	-.8 (16)	0.2 (21)	0.3 (61)	0.6 (123)	0.3 (87)	0.6 (90)	-.2 (82)	0.8 (98)	-1.6 (102)	0.3 (103)	1.0 (92)	-2.2 (102)	-2.0 (159)
7 40 N 70 W	0.1 (13)	-1.5 (25)	-.9 (20)	-.1 (21)	1.6 (12)	-.1 (13)	0.0 (13)	0.3 (25)	-2.8 (12)	-1.2 (19)	-.6 (12)	-1.7 (28)	-1.5 (16)
8 40 N 71 W	0.9 (3)	-.4 (22)	-.4 (16)	0.9 (30)	1.3 (21)	0.1 (10)	-1.1 (3)	-.1 (19)	-3.0 (12)	0.3 (14)	-2.5 (4)	-.0 (32)	-1.2 (21)
9 40 N 72 W		-1.8 (37)	1.4 (49)	1.1 (38)	0.8 (8)	0.4 (3)	-2.1 (10)	-.9 (13)	-.8 (7)	-.2 (14)	-2.4 (3)	-3.3 (11)	-1.6 (13)
10 40 N 73 W	1.1 (249)	0.6 (154)	0.5 (153)	1.0 (217)	0.9 (230)	-.2 (225)	-.0 (223)	1.2 (236)	2.2 (81)	-.8 (7)	-1.2 (4)	-3.5 (119)	-.7 (54)
11 39 N 73 W	1.2 (4)	-1.2 (43)	-.4 (34)	0.7 (22)	1.3 (27)	1.1 (15)	1.0 (18)	-.5 (21)	-1.3 (6)	-.5 (16)	-2.5 (10)	-2.8 (22)	-1.9 (15)
12 38 N 74 W	-.9 (14)	-1.8 (30)	-.1 (31)	0.7 (21)	1.3 (19)	1.1 (28)	-1.2 (27)	-.3 (23)	-1.4 (47)	-.4 (32)	0.1 (27)	-1.9 (17)	-1.9 (24)
13 37 N 74 W	1.5 (15)	-.9 (24)	0.9 (27)	-.3 (30)	1.0 (45)	0.9 (34)	-2.2 (31)	-.1 (27)	-1.6 (27)	-1.0 (41)	-1.6 (55)	-2.2 (55)	-.2 (29)
14 36 N 75 W	-2.6 (11)	-2.4 (17)	-.2 (23)	0.5 (31)	0.2 (17)	-.1 (13)	-2.6 (10)	1.1 (10)	-2.2 (9)	0.5 (12)	0.1 (11)	-1.7 (32)	-1.7 (27)
15 35 N 75 W	-.5 (10)	-1.9 (13)	1.4 (12)	1.4 (22)	2.5 (25)	-.5 (19)	0.8 (8)	0.6 (20)	-1.2 (15)	0.5 (21)	1.1 (15)	-5.3 (12)	-1.0 (12)

Figure 5.--Time-space matrix for 1977 (left) and 1976 (right) of anomaly of sea-surface temperature in degrees Celsius from the long-term mean reference period 1948-67 for fifteen 1-degree squares along the coast from Nova Scotia to Cape Hatteras (locations shown in Fig. 4). Small numbers in lower left corners of squares indicate the number of observations utilized.

southern New England to Cape Hatteras (squares 6-15), and the most intense anomalies occurring at the southern end of the region (square 14) off Virginia and North Carolina.

The previous year, 1976 (Fig. 5, right), did not show an extensive pattern of negative anomalies in the early months of the year. In fact, no significant areal pattern of negative anomalies developed until late summer and fall (August-December). In the northern section, on Georges Bank and the Scotian Shelf, a pattern of strong positive anomalies developed in the spring and summer months. This sort of positive anomaly pattern did not develop during the following two years (1977, 1978).

There appeared to be a significant difference in sea-surface temperatures between 1976 and 1978, a cooler year, with 1977 occupying an intermediate thermal regime. The difference was reflected also in the SST's observed on the NMFS spring groundfish survey cruises in the two years (Fig. 6). Spring surface water temperatures appeared to be at least $1^{\circ}C$ cooler throughout the area in 1978, and greater in some subareas, such as the Scotian Shelf and the outer shelf off New Jersey and Delaware.

Bottom Temperatures - Observations from XBT drops made along a monthly (or more frequent) transect approximately along the $71^{\circ}W$ meridian across the shelf off southern New England provide some insights concerning vatiations in water masses and circulation at the northern end of the Middle Atlantic Bight. A contoured plot of these bottom temperatures on a depth-time coordinate plane (Fig. 7) graphically reveals the annual cycle of cold temperatures in the January-April period, followed by slow warming until about October or November when rapid warming takes place as a consequence of the fall overturn. After this, cooling of the bottom water once again sets in, beginning first in shallower water and progressing seaward.

The annual temperature sequence and departures from usual conditions were described for 1978 by Crist and Chamberlin.[8] They found that the lowest bottom temperatures on the shelf occurred in late February and early March, when water colder than $2^{\circ}C$ extended offshore to about 60 m depth. The temperatures inshore of 50 m were similar to those recorded in 1977, but 1°-$3^{\circ}C$ cooler than those observed in 1974-76.

In April and May the Shelf Water mass extended much farther offshore than usual, reaching a depth of 155 m. This was similar to the depth reached in 1977, but it persisted longer in 1978. During the latter half of May the bottom trace of the Shelf Water/ Slope Water front moved inshore again and became established at normal depth by the end of the month.

Fall overturn in 1978 occurred in late November, later than in the previous four years, thus leaving bottom water temperatures cooler than normal in September and October. The annual maximum temperature achieved after the overturn was about the same as in other years. Winter cooling set in at depths less than 60 m in November and proceeded rapidly to the end of the year.

Results of XBT transects along the $71^{\circ}W$ line in January, February, and March 1979 indicated that the rate of

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[8]Crist, R. W., and J. L. Chamberlin. Bottom temperatures on the continental shelf and slope south of New England during 1978. Unpublished report. Atlantic Environmental Group, NMFS, Narragansett, RI 02882.

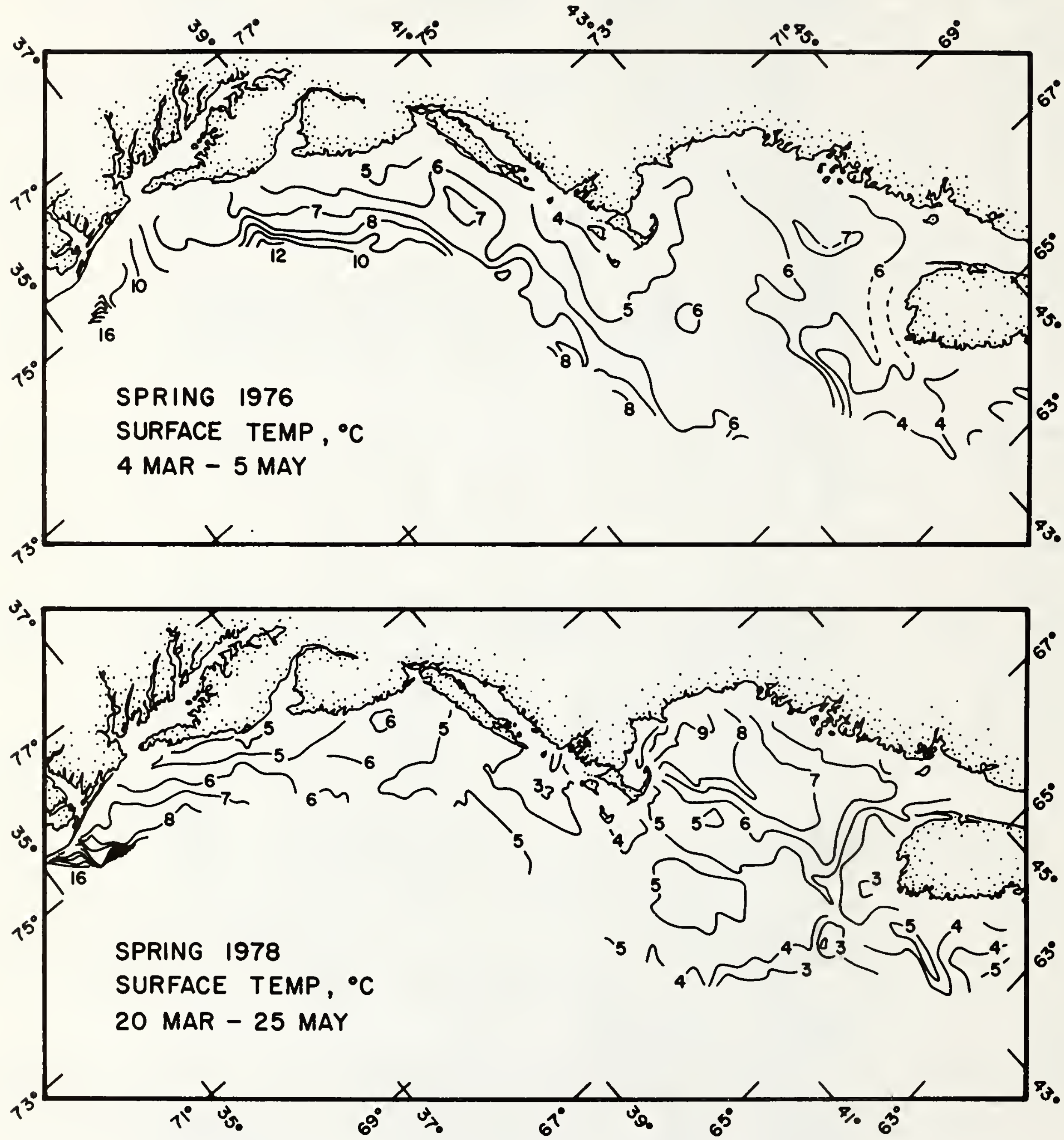

Figure 6.--Sea-surface temperature as observed on NMFS spring groundfish survey cruises in 1976 (upper) and 1978 (lower). Plot supplied by Sam Nickerson, Woods Hole Laboratory, NMFS, Woods Hole, MA 02543.

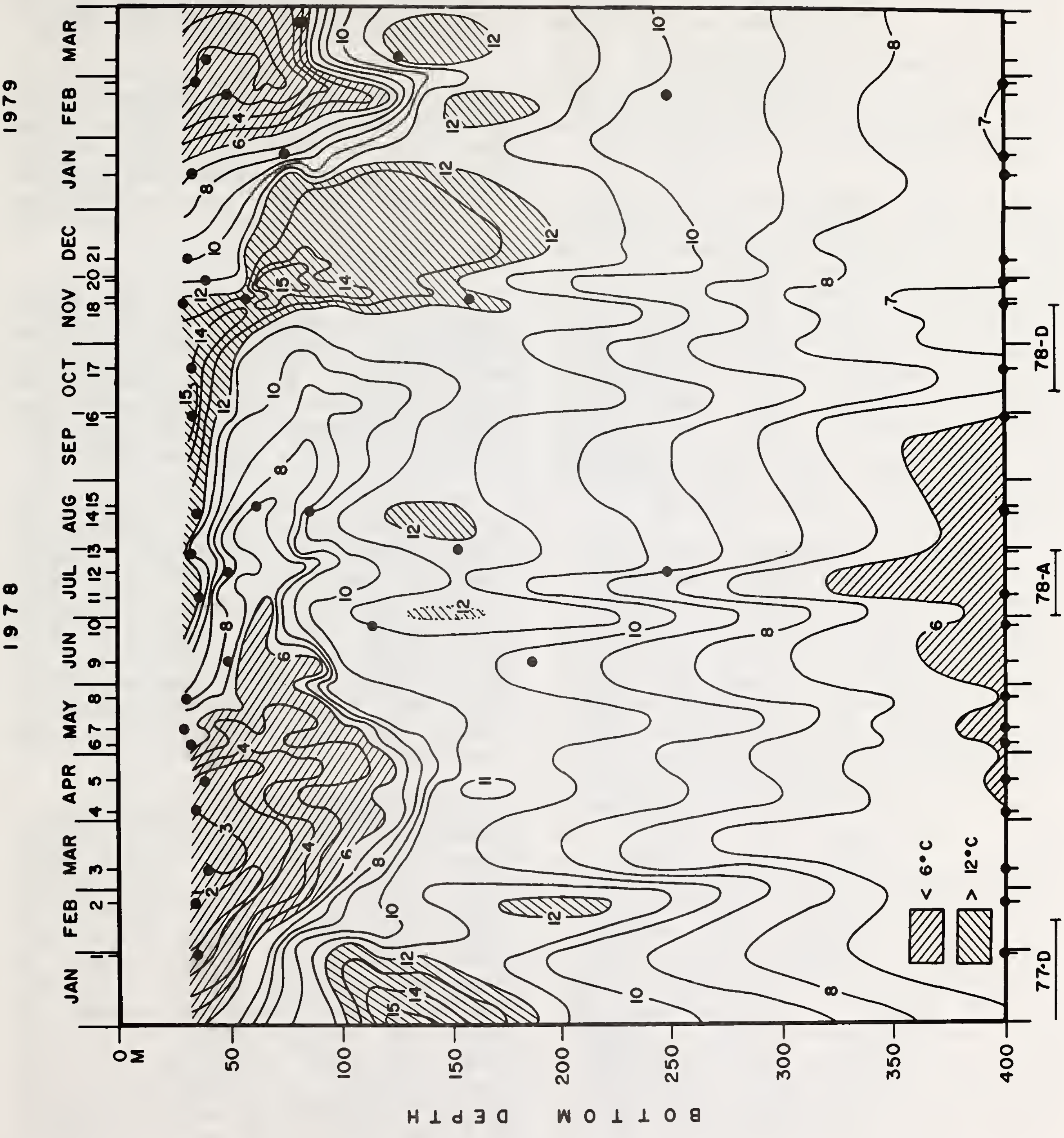

Figure 7.--Bottom temperatures in degrees Celsius along a transect at approximately 71°W across the southern New England shelf, plotted on a bottom-depth grid for 1978 and early 1979. Short vertical bars on the horizontal axes indicate time of transects. Circular dots indicate shoreward and seaward ends of transects.

winter cooling of the bottom water was unusually high until late February, when minimum temperatures (<2°C) were reached. In March some rapid warming occurred, increasing temperatures by as much as 4°C in some depths. This warming was not associated with eddy activities, since there were none in the area then.

The cooling effects of two successive unusually cold winters (1976-77 and 1977-78) appear to have affected bottom temperatures on the upper slope. During 1978 the warm band remained at about 11°C from February until June, then reached 12°C only under the influence of an eddy (78-A). During 1977 such low temperatures persisted only two months. In 1974 and 1976 temperatures in the warm band were all above 12°C, and in 1975 they were above 12°C for half of the year.

Water Column Thermal Structure - Monthly (or more frequent) profiles of temperature obtained with XBT's dropped from ships of opportunity transiting the Shelf Waters off New Jersey in 1978 have been analyzed by Cook and Hughes.[9] The 19 transects they analyzed revealed that water column temperatures in the early months of 1978 (vertically isothermal conditions) were warmer (by about 2°C) than those in early 1977, which were about 3°C colder than normal. By May, stratification had progressed far enough to from the "cold core" characteristic of the shelf in the Middle Atlantic Bight. Temperatures in the bottom cold cell in June, however, were as cold as those measured in 1977 (<4°C). At about the same time, the minimum cold cell temperatures off southern New England were <6°C and those off the Virginia Capes were <8°C. Apparently, the winter conditions of early 1978 were not as severe, but of longer duration, a condition which yielded about the same temperature regime as in 1977 in the cold cell in early summer (Cook 1978).

The cold core warmed slowly through the summer, but minimum temperatures remained 1°-2°C cooler than those in any of the previous four years. However, bottom temperatures inshore of the cold core (depths less than 40 m) were similar to those of the other four years.

The fall overturn off New Jersey began in October, with the bottom temperature reaching >10°C by the end of the month. By mid-December it was almost complete, with the water mass nearly isothermal vertically at 10°-12°C on the central and inner shelf.

Transect stations occupied in early 1979 showed that cooling proceeded rapidly in January and February, yielding temperatures in early March ranging from 2°C inshore to 7°C at the shelf break, much the same as in 1978. The weather changed dramatically in March, however, and by the end of the month the water mass had warmed by 2°-4°C and some stratification was appearing.

Shelf Water/Slope Water Front - Chamberlin (1978) reported on the unusual distribution of cooler Shelf Water in the Slope Water area off the Middle Atlantic Bight, as detected in satellite infrared imagery. He found the offshore excursion, which began in March, most accentuated in April, when the front was 110-180 km farther off shore than at any other time since 1973 when satellite monitoring of this feature began. At times during this period, portions of the front apparently were contiguous with the northern

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[9] Cook, S. K., and M. M. Hughes. Water column thermal structure across the shelf and slope southeast of Sandy Hook, NJ in 1978. Unpublished report. Atlantic Environmental Group, Narragansett, RI 02882.

edge of the Gulf Stream. During the rest of the spring and summer of 1978 the front was located closer to the shelf edge than in March and April, but still seaward of its average position.

The deepening of the Shelf Water/Slope Water front (offshore displacement) which occurred in July and October apparently was caused by entrainment of Shelf Water by eddies 78-A and 78-D.

An analysis of variation of the location of the Shelf Water/Slope Water front in 1978 by Hilland and Armstrong (see footnote 7) included a discussion of frontal locations off Sandy Hook (frontal crossings of the 130° heading line from Sandy Hook). They found that significant seaward excursions (up to 150 km) occurred from late February until July and once again in December. Satellite infrared imagery obtained during occasional cloudless periods in the first three months of 1979 showed the front to be a short distance inshore of its average position in early February. In mid-March it was found far offshore (125 km) of its average position, but by the end of the month it had returned to the vicinity of its average position.

Eddies - The most apparent differences between 1977 and 1978 seen in the temperature transects, however, were the absence of eddy signatures and the seaward excursion of the Shelf Water/Slope Water front in March-July 1978. Eddy occupation of Deepwater Dumpsite 106, at the seaward end of the transect, dropped from 67% of the time in 1977 to about 34% of the time in 1978. Apparently the two events, absence of eddies and excursion of the front, are related. At least they were coincident in 1978, with the front reaching a point more than three standard deviations seaward of its mean position (Wright 1976) during the period of eddy absence.

In their summary of warm core Gulf Stream eddy activity for 1978, Celone and Chamberlin[10] reported that there were two eddies in the Bight in January and February, then none from March until June, when an eddy (78-A) appeared off southern New England (Table 7). From that time on, there were one or more eddies in the bight for the rest of the year. Satellite imagery for the first three months of 1979 showed that there were no eddies in the Bight and that the Shelf Water/Slope Water front moved far seaward and was in contact with the Gulf Stream most of January and February. In early March the front returned to a nearly normal position near the edge of the continental shelf, only to move offshore to about 125 km by mid-March and return to the average position again by the end of the month. The absence of eddies probably does not cause the offshore extension of Shelf Water, although there seems to be a correspondence between the two phenomena. The extension of Shelf Water may result from advection of cooler water into the Slope Water from the Scotian Shelf or farther north.

Wind-Driven Transport - In the area off southern New England (40°N, 70°W) transport during April through September 1978 was generally southward, conforming approximately to the 10-year mean (Fig. 1). However, it was twice as strong as usual in April and June, weaker in May, July, and August, and normally weak in September. October and November showed neglible transport. In December, transport was in the usual south-southwestward direction, but at

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[10]Celone, P. J., and J. L. Chamberlin. Anticyclonic warm core Gulf Stream eddies off the northeastern United States during 1978. Unpublished report. Atlantic Environmental Group, NMFS, Narragansett, RI 02882.

Table 7.--Eddy positions at mid-month with respect to zone during 1978 and early 1979

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1.						78-F		78-G			78-I	78-I			
2.					78-C	78-E	78-F	78-F					78-I	78-I?	
3.				78-B	78-B	78-D	78-E	78-E							78-I
4.				78-A	78-A		78-D			78-H	78-H				
5.						78-A	78-A	78-D	78-D						79-A
6.								78-A		78-D	78-D				
7.	77-D	77-D							78-A			78-D			
8.										78-A					

1. Eastern Nova Scotia
2. Western Nova Scotia
3. Eastern Georges Bank
4. Western Georges Bank
5. Southern New England
6. Long Island, New York Bight
7. New Jersey, Delaware
8. Virginia

more than four times normal strength. The January 1979 direction was normal at two-thirds strength. Transports in February and March 1979 were quite unusual in magnitude; the former was about four times average and the latter was about one-fourth average.

Off the middle Atlantic States (35^{o}N, 75^{o}W), March transports were usually low (one-sixth average), April and May were near normal, June weaker and more to the south, and July through October and December about normal, but November deviated considerably from the normal southwestward transport to northwestward, with about 40% greater magnitude.

River Runoff - precipitation patterns, as reflected by river runoff, were anomalous in some areas during some months in the 1978-winter 1979 period. In the Chesapeake Bay during calendar year 1978, freshwater runoff was the fifth highest of the 29 years of record (Fig. 8, upper). The third and fourth record high years occurred during the wet climate regime of the early 1950's. The first and second highest annual averages resulted from the deluges of hurricane Agnes in 1972 and hurricane Eloise in 1975. The excessive runoff in spring 1978 was due to an unusually cold and snowy winter. Late spring and summer also were rainier than usual, so that surplus runoff through August far exceeded the deficit in fall. Precipitation was unusually heavy during the stormy winter of 1978-79, producing record runoff in March 1979 which exceeded the previous record streamflow of March 1978.

Runoff into Long Island Sound can be gaged from rivers in Connecticut (Fig. 8, lower). From April 1978 through June, Connecticut streamflow was within normal range or slightly above. During July, runoff was slightly lower than average. It was nearly normal in August, but low in September and October. During November, precipitation was sparse and streamflow was deficient until the end of the year. Two heavy rainstorms in January brought runoff to five times normal that month, with widespread flooding. Streamflow was normal in February and well above average in March.

Runoff from rivers in Connecticut was similar to that of the Chesapeake Bay in trend. However, the spring peak flow into Chesapeake Bay occurred in March while the peak flow into Long Island Sound was in April, the normal times of peak flow into these two water bodies. The frontal activity of May, so evident in the Chesapeake, was concentrated in the middle Atlantic States and did not cause unusually high runoff in Connecticut.

Both areas showed a runoff peak in August due mainly to heavy rainfall the first week of that month. September is normally the month of lowest freshwater flow into both Long Island Sound and Chesapeake Bay; however, in 1978 the month of lowest freshwater inflow into Chesapeake Bay was October. The August-December runoff in Connecticut was much lower than average, even lower than in 1977. Runoff in both areas rose sharply after November to the January peak. The streamflow was lower in February 1979 due to frozen conditions, and much higher in March due to snowmelt, although not a record in Long Island Sound.

South Atlantic Bight

Aside from satellite imagery, ship observations of meteorological conditions, coastal weather station data, and ship observations of sea-surface temperature, no routine monitoring information is available to us from the South Atlantic Bight. The coastal weather station observations of air temperatures and computed wind-driven transports were discussed earlier in this report. The lack of subsurface monitoring data precludes analysis of water mass changes and circulation.

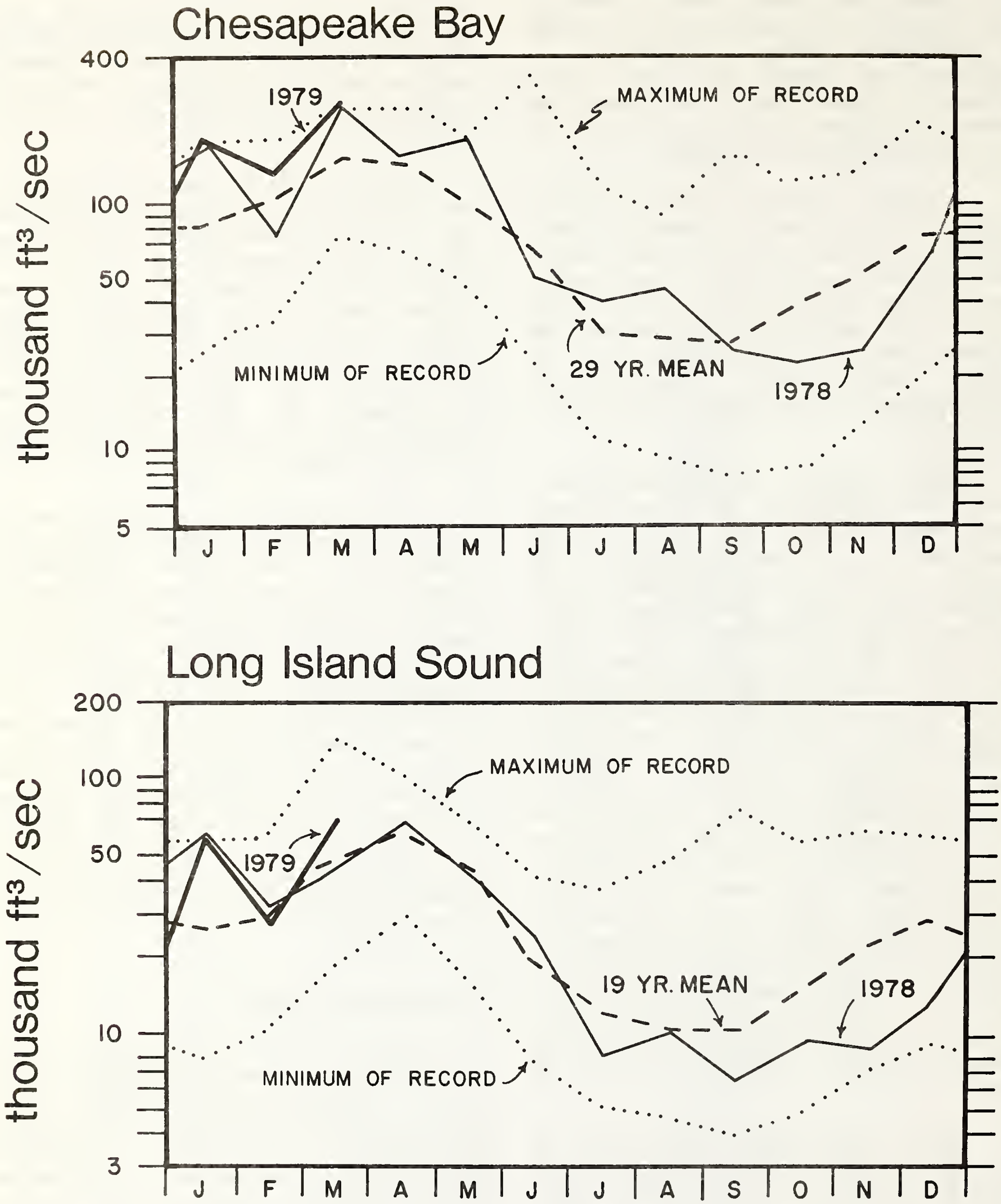

Figure 8.--Monthly average streamflow in thousand cubic feet per second into Chesapeake Bay (upper) from data supplied by the U.S. Geological Survey District Office, Towson, MD 20204 and into Long Island Sound (lower) from Water Resources Conditions in Connecticut, June 1979, U.S. Geological Survey District Office, Hartford, CT 06103.

Sea-Surface Temperature - A space-time plot of coastal SST anomalies from Cape Hatteras to Cuba (Fig. 9) showed a pattern of negative anomalies in the winter and spring 1978. The coldest condition occurred in February-March, stretching from Cape Hatteras to northern Florida (square 8). By June the extreme conditions abated for the remainder of the year. The strongest negative anomalies were found in squares 1 and 2, and were apparently a manifestation of cold Virginian Shelf Water moving southward to Cape Hatteras and beyond.

Area average monthly anomalies of SST, pooled for 21 one-degree squares, generally were small in the South Atlantic Bight (Table 8). Two periods of negative anomalies occurred, January-May 1978 and January-March 1979. In both periods, February showed the strongest anomaly. The negative anomaly patterns in 1978 and 1979 corresponded reasonably well with the air temperature anomaly patterns (Table 1) for that area, when allowance is made for the longer recovery (warming) period required by the coastal waters.

Wind-Driven Transport - In the South Atlantic Bight (30°N, 80°W), transport was to the right of the normal direction in April and May, but of average strength (Fig. 1). Transports of June through October were all normal in direction, but in August and October were half again stronger than averages from the 10-year base. November transport was twice as strong and directed about 20° to the right of normal, with December normal in direction and magnitude. January-March 1979 transports were smaller than the average, virtually insignificant in magnitude.

Gulf of Mexico

Sea-Surface Temperature - During the early months of 1978 the waters of the northern Gulf of Mexico were colder than normal, with the strongest negative anomalies occurring in the eastern half in February. The colder than normal pattern began to break up in April, and greater than normal warming produced positive anomalies by June. A pattern of weakly positive anomalies occupied the area for the remainder of 1978. In January 1979 a pattern of negative anomalies reappeared, though weaker than in 1978. This pattern was again most intense and widespread in February, though not to the extent of the previous year.

Table 8.--Average coastal sea-surface temperature anomalies (°C) for an area of 21 one-degree squares in the South Atlantic Bight in 1978 and January-March 1979

1978:	Jan	-1.05	1979:	Jan	-0.78
	Feb	-0.24		Feb	-1.36
	Mar	-0.96		Mar	-0.85
	Apr	-0.62			
	May	-0.68			
	Jun	+0.13			
	Jul	+0.18			
	Aug	-0.08			
	Sep	+0.28			
	Oct	-0.23			
	Nov	+0.14			
	Dec	+0.90			

		1978												1979		
	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1 36 N 75 W		-4.2 13	-4.0 31	-2.8 30	0.3 30	-2.8 34	-2.4 29	-.9 14	-.7 2	1.0 11	-.6 16	-.1 14		-.1 10	-3.0 17	-2.6 24
2 35 N 75 W		1.8 19	-7.7 19	-5.7 18	-4.5 24	0.7 18	0.8 6	1.7 14	1.0 13	1.8 16	-.9 16	-2.0 10	4.1 10	0.6 16	-5.5 18	-1.8 22
3 34 N 76 W		-2.7 4	-1.1 9	0.7 9	0.0 4	-2.1 29	-1.7 7	0.1 6	0.1 5	0.8 16	0.7 9	-.4 2		0.4 3	-2.6 7	-2.2 14
4 33 N 77 W		-3.9 12	-4.0 9	-1.4 11	-.8 8	-3.3 10	-.6 6	-.1 5	-2.1 5	0.6 5	-1.5 18	-.8 6	1.9 8	-1.5 13	-2.5 11	-3.0 9
5 33 N 78 W		-.1 1	0.2 4	-2.7 3			0.2 2	-.9 4	0.8 1	0.2 6	-2.9 1		2.4 9	-.3 2	-1.9 4	-1.3 5
6 32 N 79 W		-1.3 2	-2.8 7	-1.9 6	-3.7 11	-2.8 7	0.4 6	0.6 8	1.9 2	1.0 8	-.6 6	-1.0 8	1.4 8	-3.5 11	-3.9 9	0.3 11
7 31 N 80 W		-3.6 8		-2.9 4	-1.1 4	-2.6 8	0.6 9	1.7 3	0.5 2	0.5 4	0.4 5		0.9 4	-.5 18	-4.2 8	-1.4 5
8 30 N 80 W		-2.9 8	-.4 19	-1.7 15	-.1 12	-.1 22	1.1 15	-.3 7	0.4 5	-.2 7	-1.5 6	0.7 8	2.1 15	0.2 9	0.4 3	-1.2 15
9 29 N 80 W		-.1 2	1.2 15	-.0 26	-.6 7	-1.0 10	0.4 6	0.7 5	0.8 6	0.5 6	-.3 4	0.9 5	1.1 4	-.4 4	0.7 6	-1.4 3
10 28 N 80 W		-.4 3	-1.0 5	-.0 7	0.9 6	-.6 6	1.0 1	0.2 4		-.3 4	0.2 6	-.4 4	0.6 5	-.3 7	-.4 8	-.3 6
11 27 N 80 W		-.0 3	-1.2 4		0.7 2	-.1 5	0.7 1	-.7 2	-.8 2	1.0 4	0.5 3	1.2 3		-.7 4	-.1 3	-1.2 3
12 26 N 79 W		-.9 15	-.8 21	-.6 23	-.7 21	0.5 20	0.7 15	1.3 20	0.4 8	-.2 15	-.1 18	0.8 26	1.1 19	0.1 15	0.2 17	0.7 12
13 25 N 80 W		-.2 5	-.7 6	-.2 12	-.2 11	0.4 13	0.8 18	1.7 9	0.1 7	-.2 8	0.3 13	0.8 9	-.4 10	1.3 5	-.5 11	-1.2 14
14 24 N 80 W		-.2 4	0.1 15	-.6 9	-.5 9	1.1 19	0.2 22	1.2 16	-.1 8	0.2 8	-.4 11	0.5 18	1.1 12	0.5 14	-.0 6	0.3 13
15 23 N 81 W		1.1 3	1.1 6	1.8 4	0.7 8	0.4 5	0.8 6	-.2 8	0.1 3	-.9 4	0.4 5	0.2 3	1.5 5	0.1 3	-.6 2	-.2 6

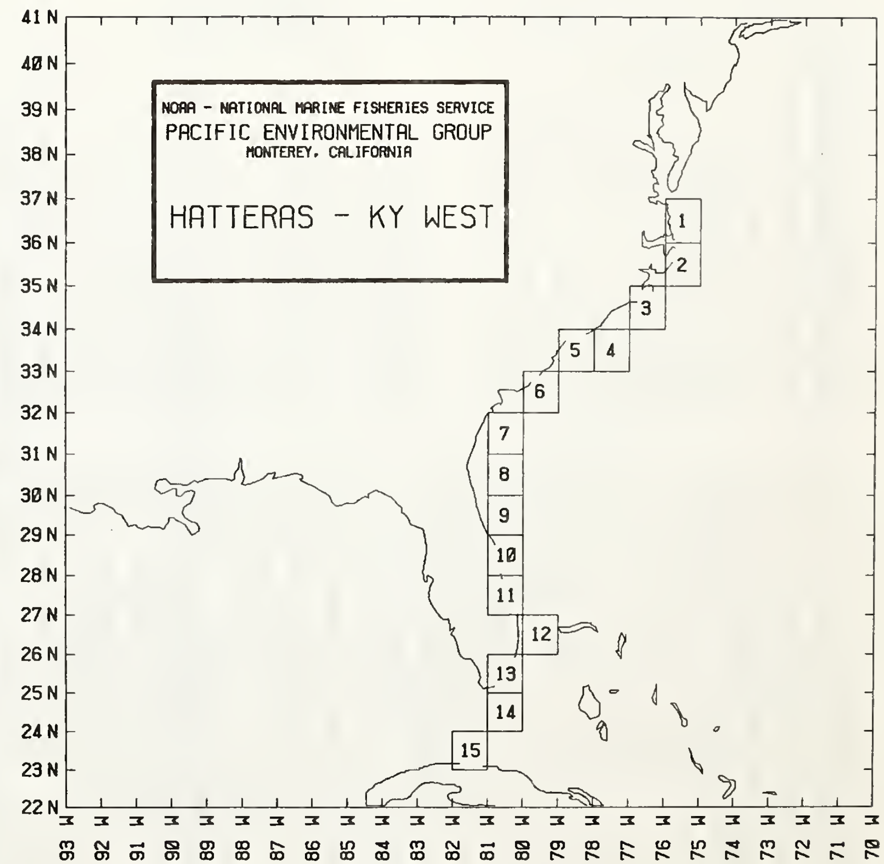

Figure 9.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (left) in degrees Celsius from the long-term mean reference period 1948-67 for fifteen 1-degree squares along the coast from Cape Hatteras to Cuba (locations shown at right). Small numbers in lower left corner of matrix squares indicate the number of observations utilized.

Circulation - The principal circulation feature in the Gulf of Mexico which can be monitored, albeit sketchily, is the Eastern Gulf Loop Current, which enters through the Yucatan Channel, extends a variable distance northward into the Gulf, and then turns clockwise to the east and south and exits through the Straits of Florida. Based on plots derived from satellite imagery by the National Environmental Satellite Service Field Service Station in Miami, FL, and hydrographic data collected in the northern Gulf, the extension of the Loop Current northward into the Gulf in 1978 and early 1979 been portrayed by Brucks[11] (Fig. 10). He pointed out that the maximum northward extension of the Loop Current occurred in the spring and early summer. Hydrographic data collected just south of the Mississippi Barrier Islands in June and July (about 30°N) showed water properties characteristic of the Loop Current, even though satellite imagery revealed nothing, because of strong surface heating. Haddad and Carder (1979) reported a red-tide bloom, apparently associated with an invasion of west Florida Shelf Water by Loop Current Water, from Charlotte Harbor to about 90 km north of Tampa Bay (27°-29°N). In October, when satellite imagery was effective once again, the Loop had withdrawn to about 28°N and eventually reached a minimum of about 25.5°N in November. Following that, it extended northward again to a maximum of about 28.3°N in early April, then rapidly retreated to a minimum of about 24.3°N late in the month. The active advances and retreats of the Loop in late 1978 and early 1979 spawned many eddies which remained north of the main current and were detected as far north as 29°35'N.

Wind-Driven Transport - In the eastern Gulf of Mexico (27°N, 84°W), April's transport was about half average strength and about 15°-20° to the left, while May's was about two-thirds average and rotated to the right about the same amount. In June, transport was slightly stronger and a few degrees left of average. These were all insignificant variations. July showed exactly average direction and two-thirds of the month's very low average strength. Transport picked up in August to twice average strength and about 20° to the left; that variation in direction prevailed to the end of the year. Transport in September was below average strength, but in October was more than three times the average. Transports during the final two months of the year were of normal strength. In January-March 1979 transports were not highly unusual in magnitude or direction, although that of March was rotated left to west of north.

In the central Gulf (27°N, 90°W), transport in April was essentially average, in May, June, and July about 20% stronger than normal and slightly to the right, while August's transport was offset about 20° to the right and was about three times normal strength. The remaining months showed transports about one and one-half times average strength and near normal in direction, except for November when the direction was due north instead of the normal north-northwest by north. This could be due to the expansion northward and westward of the normal Bermuda high atmospheric pressure system. The March 1979 transport was essentially as the long-term average.

In the western Gulf (27°N, 96°W), transport values were near normal during April-December, except for March and June when they were about half the 10-year mean values. The transport directions were nearly normal for the period except for October-December when

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[11] Brucks, J. T. National Fisheries Engineering Laboratory, NMFS, Bay St. Louis, MS 39529.

they were up to 20° left of normal. Transport in January and March 1979 varied considerably in direction from the long-term average, the former about 30° to the westward and the latter about 30° to the eastward; February's transport was normal in direction at half normal strength. In addition, the March magnitude was about 50% larger than the average. The variations from normal transport in April-December 1978 were not large.

River Runoff - The record monthly mean flows of the Mississippi River at Tarbert Landing, MS, in 1978 and early 1979 (Table 9) provide a striking contrast in early spring conditions. Flows in March-May 1978 ranged from 514,000 to 872,000 ft^3/sec, but in 1979 they ranged from 1,146,000 to 1,299,000 ft^3/sec. In each case the largest flow was in April; the April 1979 flow was near the median of the 48 years of record. This was about double the flow of April 1978 and would be expected to have affected salinity-sensitive organisms in the Mississippi Delta area.

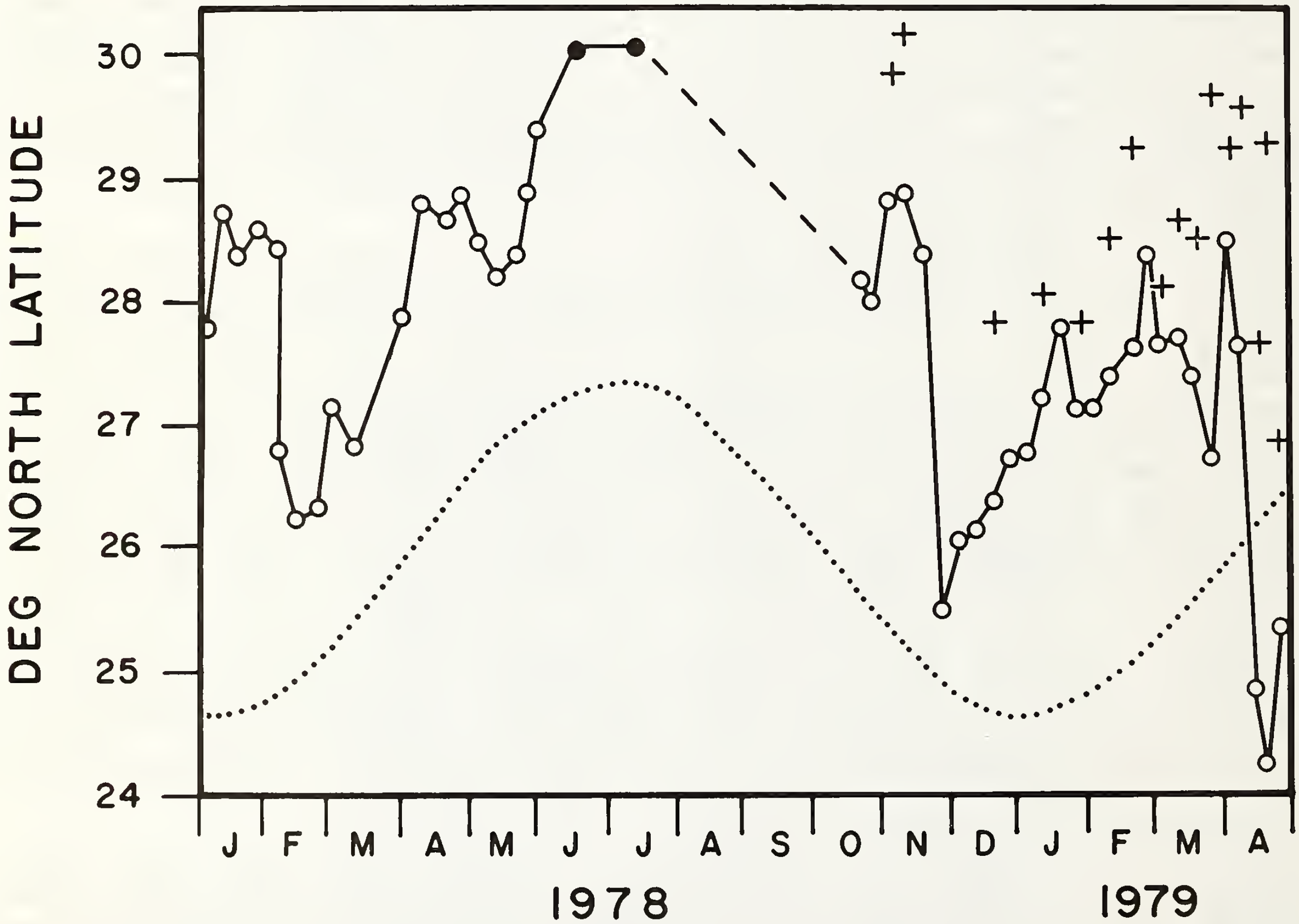

Figure 10.--Extension of the Eastern Gulf Loop Current into the Gulf of Mexico. Open circles indicate locations determined by satellite infrared imagery, closed circles indicate locations determined by hydrographic surveys. Crosses indicate the northern edge of current fragments or eddies. Plot supplied by John Brucks, National Fishery Engineering Laboratory, NMFS, Bay St. Louis, MS 30530.

Table 9.--Monthly average flows (ft^3/sec) of the Mississippi River measured at Tarbert Landing, MS

1978:	Jan	510,000	1979:	Jan	702,000
	Feb	526,000		Feb	644,000
	Mar	537,000		Mar	1,043,000
	Apr	855,000		Apr	1,288,000
	May	768,000		May	1,234,000
	Jun	507,000		June	801,000
	Jul	349,000			
	Aug	297,000			
	Sep	247,000			
	Oct	217,000			
	Nov	216,000			
	Dec	647,000			

Source:
U.S. Army Corps of Engineers
P.O. Box 60267
New Orleans, LA 70160

Effects on Fisheries - Brucks (see footnote 11) observed also that variations in the Loop Current's strength and its extension into the Gulf must strongly influence the environment of the biota of the continental shelf, as well as the distribution of pelagic species associated with the current itself. A case in point, brought to our attention by Van Devender,[12] is the fluctuation in brown shrimp abundance. Survey samples included large numbers of shrimp two weeks before the discovery of Loop Water off Mississippi. The number of captured shrimp dropped off dramatically concurrent with the arrival of Loop Water, so that the total 1978 catch of Gulf shrimp (248.3 million pounds, heads on) was down 7% from the record year 1977. Landings declined from 1977 in all Gulf States except Louisiana, where the catch was up very slightly to 104.4 million pounds (Commerce 1979).

Reasons for the good catch of brown shrimp in 1978 are related to a combination of factors. A large area of nursery grounds was available to the shrimp during the spring, due to relatively low spring rainfall and river discharge which resulted in the relatively high salinities preferred by the shrimp larvae in their usual nursery areas and in the upper estuaries as well, combined with relatively warm spring water temperatures and very few hours after April when water temperatures dropped below 20°C, enhancing shrimp growth.

An outstanding catch of 819,700 mt of Gulf menhaden was made in 1978, almost double the 1977 catch of 447,100 mt (Commerce 1979). Landings in June 1978 were the largest in the history of the fishery. Reasons for this highly productive year are speculative at best. It is curious to note that the June and July encroachment of Loop Current Water onto the Mississippi shelf may have been detrimental to shrimp distribution and production while providing favorable conditions for the menhaden fishery. The consensus among fishermen and fishery scientists is that the high production was a result of good weather conditions for fishing and the apparently very large 1976 and 1977 year classes that produced an abundance of 1- and 2-year-old fish for the 1978 fishery.

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[12] Van Devender, T., Gulf Coast Research Laboratory, Ocean Springs, MS 39564. Personal communication.

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ATMOSPHERIC CLIMATOLOGY AND ITS EFFECT ON SEA-SURFACE TEMPERATURE WINTER 1978 TO WINTER 1979

Robert R. Dickson[1] and Jerome Namias[2]

Previous reports in this series described the progressive north-south amplification of the Northern Hemisphere circulation in 1976 and 1977 compared with the abnormally strong westerly flow of the preceding 5 years (Dickson and Namias 1979a, 1979b). In 1978 this amplified circulation type was generally maintained and the overall pattern of the hemispheric circulation itself showed some elements of similarity to that of the previous year.

This year-to-year similarity is illustrated in Figure 1, A and B, which compares the mean annual distributions of 700 mb height and height anomaly in 1977 and 1978. In both years, cells of negative height anomaly extended over the northern North Pacific with centers to the south of the Aleutians (-70 ft and -90 ft in the annual mean, respectively). In both years, two further mean troughs centered over New England/Newfoundland and at a variable location between the northwestern European littoral and northwestern Russia completed a discontinuous belt of low pressure at midlatitudes which encircled extensive high pressure anomaly cells at higher latitudes (centered over western Canada/Alaska and southern or eastern Greenland). Again in both years intensified subtropical highs are evident to the south of the Aleutian trough in mid-Pacific.

The corresponding mean annual distributions of sea-surface temperature (SST) anomaly for the two years are compared in Figure 2, A-B and C-D. As might be expected, these reflect the common tendencies of the circulation by showing essentially similar patterns of SST anomaly in 1977 and 1978. Common elements are the vast area of colder than normal surface waters in the northern and western Pacific, mainly the product of extreme storm activity (from 2 to 3 standard deviations in excess of normal) in mid-Pacific during the respective winter seasons, the general but more localized mean warming in the southeastern Pacific off Baja California, and the center of intense warming off the North American Atlantic coast which continued to dominate the field of SST anomaly in the Atlantic sector in the two years under discussion. Differences between the two years are also evident. In 1978, for example, each of the three main centers of SST anomaly is shown to be more extensive in distribution but somewhat weaker in amplitude than in the preceding year. Further important differences will be described below in the season-by-season breakdown of these mean annual patterns.

Winter

The extreme climatic events of winter 1978 have already been described in detail (Dickson and Namias 1979b) and are resummarized here only insofar as they represent important antecedent conditions for the present report. As with the annual mean, Figure 3A shows that the mean winter distribution of

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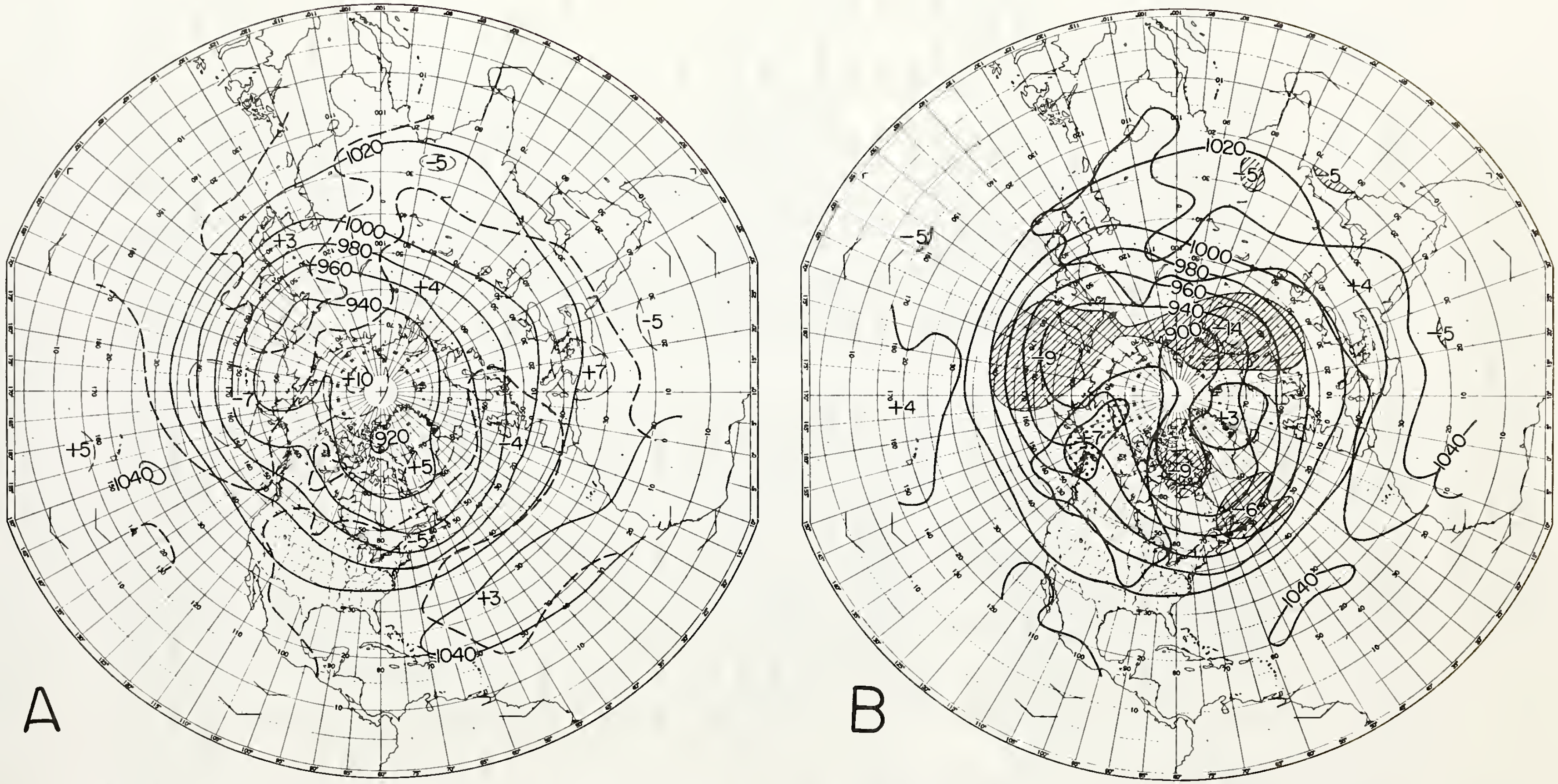


1977 MEAN ANNUAL 700 mb HEIGHT & ITS ANOMALY (feet÷10)

1978 MEAN ANNUAL 700 mb HEIGHT AND ITS ANOMALY (feet÷10)

Figure 1.--Mean annual distribution of 700 mb height and its anomaly (feet/10) for:
(A) 1977, and (B) 1978.

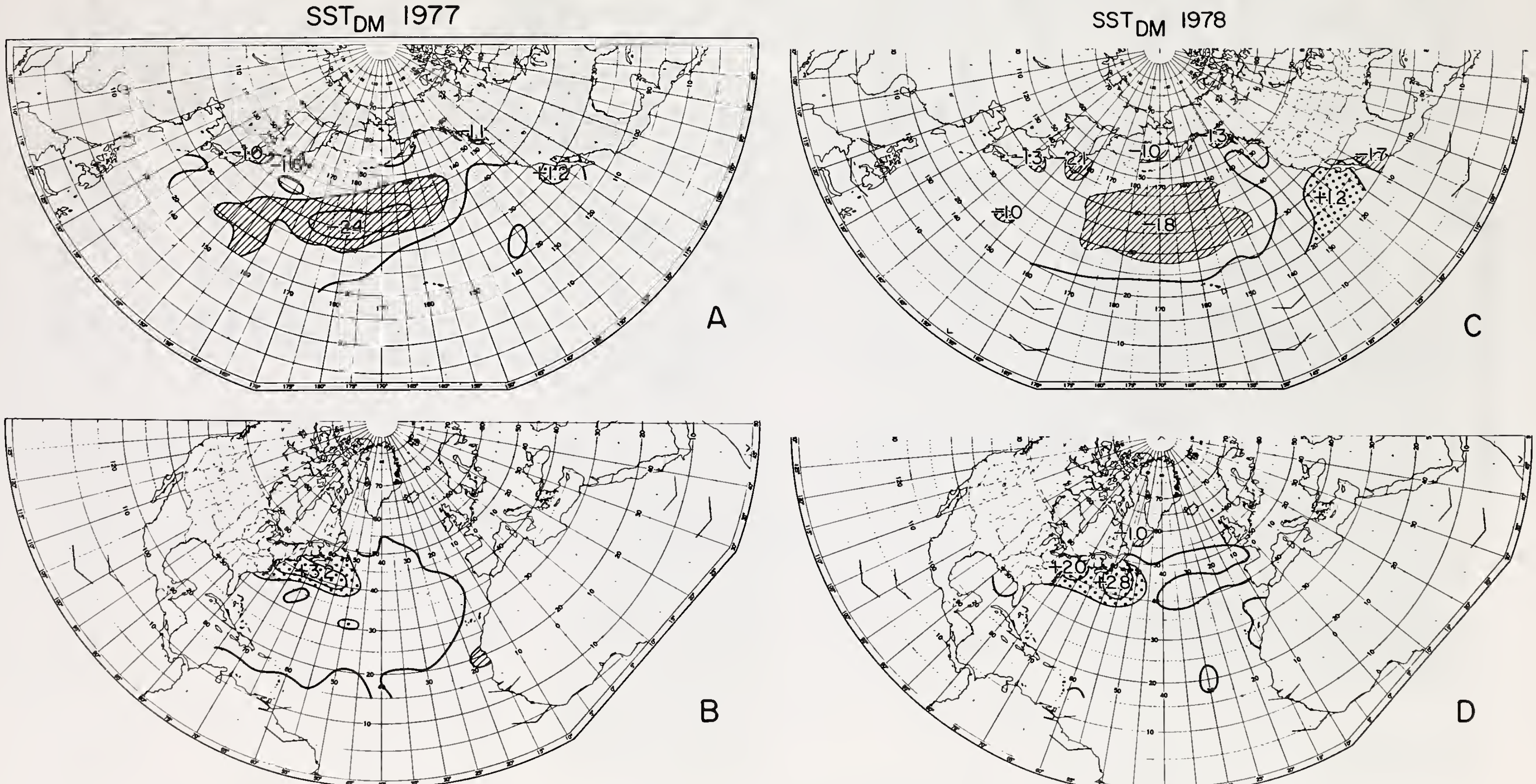


Figure 2.--Mean annual distribution of sea-surface temperature anomaly (^{o}F) for: (A, B) 1977, and (C, D) 1978.

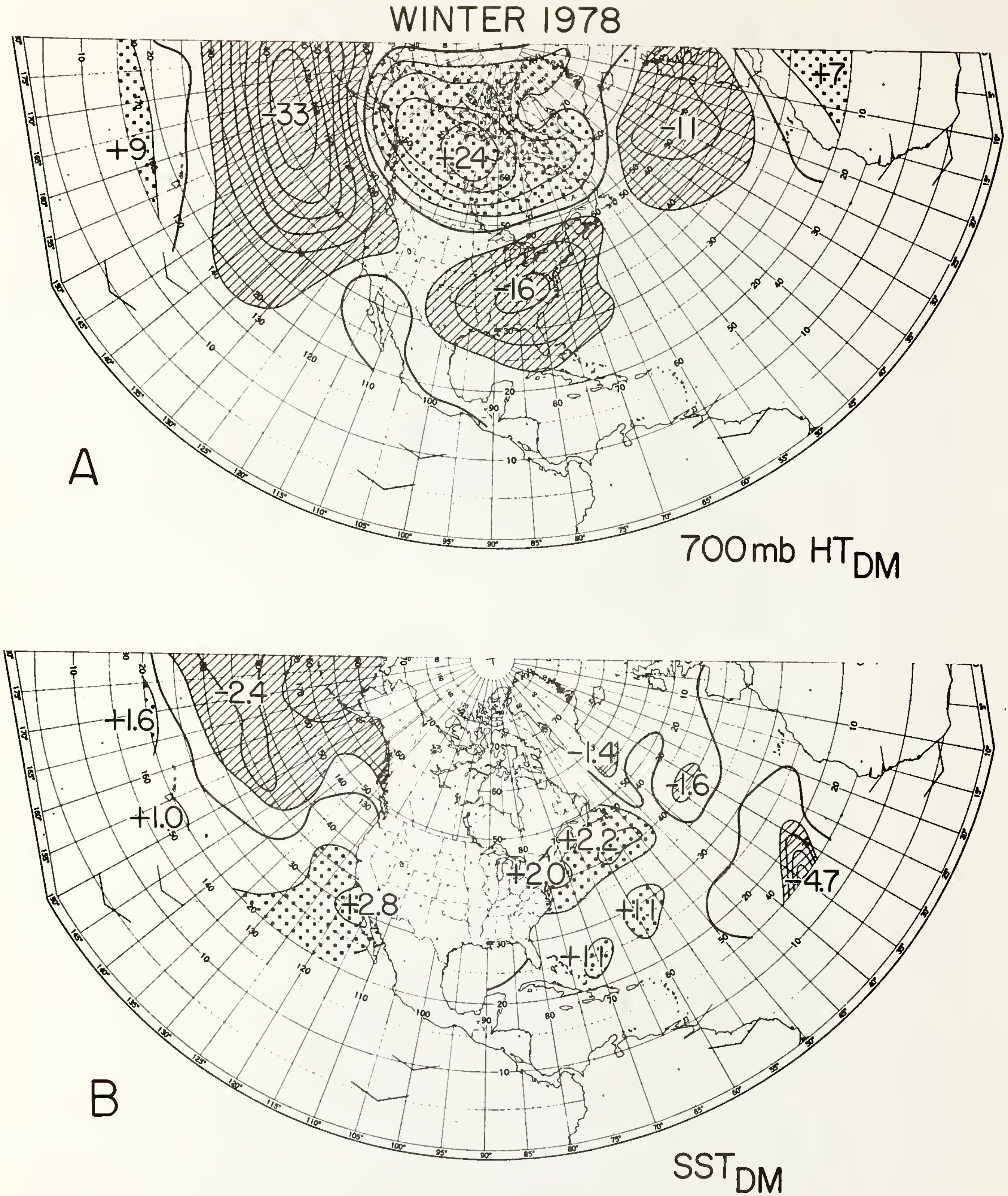


Figure 3.--Mean distribution of: (A) 700 mb height anomaly (feet/10), and (B) sea-surface temperature anomaly (^{O}F) in winter 1978.

700 mb height anomaly was dominated at high latitudes by an intensive anomalous polar ridge (+240 ft in the seasonal mean) over west central Canada, and encircled at midlatitudes by a chain of deep, southward-displaced troughs which extended across the entire northern Pacific (-330 ft), eastern North America (-160 ft), and eastern Atlantic (-110 ft). The Canadian ridge and the Pacific and North American troughs were all extreme features averaging 2 standard deviations from normal (Wagner 1979a), which generated or reinforced widespread surface cooling at midlatitudes over both oceans and over much of the intervening continent.

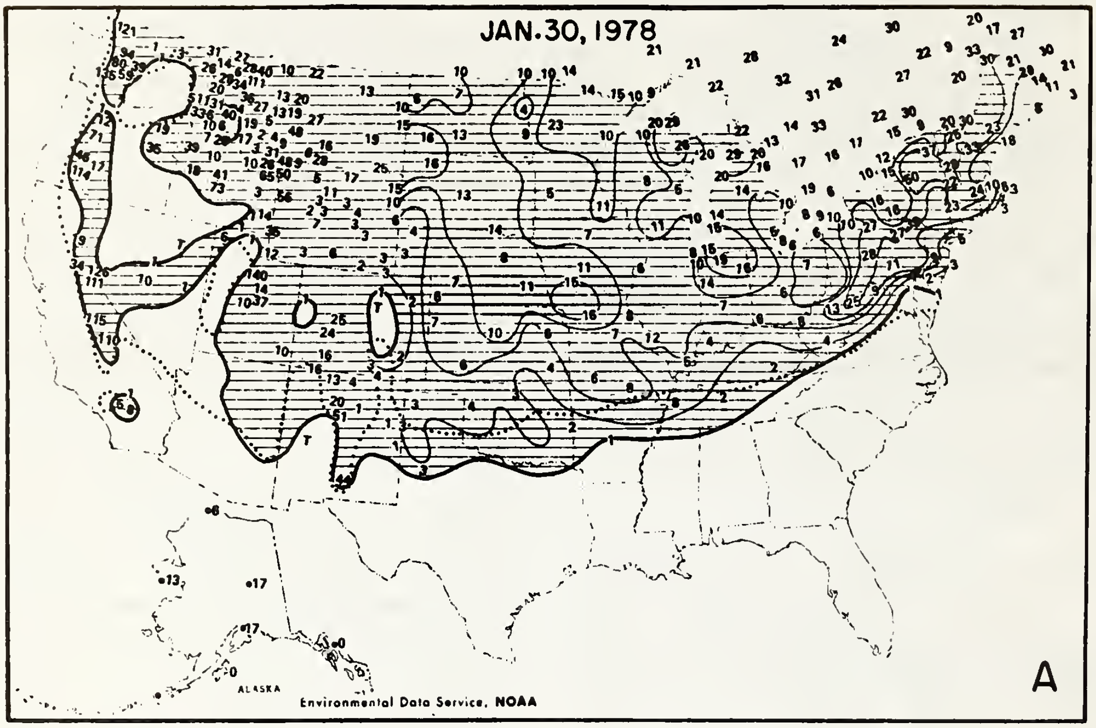
Under the intense and persistent Aleutian trough, the enhanced cloud cover, increased sensible and latent heat transfer, cold frontal activity, and surface water divergence had the effect of further extending the cold water belt which had persisted in the northern Pacific since its record extent in the summer of 1976 (Namias 1978). Over North America, the Canadian ridge and deep east coast trough combined to spread frigid arctic air masses southward at surface level across much of the continent east of the Rockies, and this refrigerated air was frequently overridden by moist Pacific currents moving along a depressed westerly axis across the Gulf of Mexico to the Ohio Valley. The result was record or near-record snows from Texas to the Great Lakes and eastward to New England (Fig. 4), with snow lying on the ground in parts of the Central Plains and Midwest for more consecutive days than ever before recorded (Ludlum 1979). Finally, although the northwest Atlantic retained an apparent warmth (discussed in Dickson and Namias 1979b), the band of cool surface conditions at midlatitudes continued east of 50^{o}W, where a mean trough brought extensive, though not very intensive, cooling to the surface waters of the northeastern Atlantic.

Spring

These well-entrenched general features of the surface temperature field persisted in recognizable form into spring, reversing (at least initially) the normal tendency for minimum persistence at this "transitional" time of year. Anomalous troughing continued to occupy the northern North Pacific (Fig. 5A), further intensifying the surface cooling south of the Aleutians; core anomalies of -3.2^{o}F were generated in a zone of strengthening westerlies between the Aleutian trough itself and an expanding subtropical ridge to its south (Fig. 5B). Off southern California, the winter zone of warm surface waters maintained its intensity and built steadily to the north and west; the immediate cause was the anomalous southerly airflow around the Aleutian trough which brought an inhibition of coastal upwelling, a reduction in sensible and latent heat transfer, and an increased northward advection of warm surface water along the western seaboard. However, with the intensification of cooling in mid-Pacific and the expansion of warming in the southeast, the sharpened east-west temperature gradient in the eastern Pacific was itself compatible with maintaining the upper-level southerly airflow in this sector.

Over the North American continent the massive Canadian ridge of the winter season evolved in spring to form two connected cells of high pressure anomaly centered over the Bering Strait (+150 ft) and the U.S.-Canadian border (+60 ft; Fig. 5A). The splitting of the westerlies around the latter center maintained the winter tendencies for mildness in the western states and for a depressed axis of westerlies across the south, with heavy precipitation over California (twice normal, as in the winter). In the east, the winter cooling was also strongly maintained into spring, with the same weak ridge over the U.S.-Canadian border tapping cold arctic air into the eastern states and with its passage over late season

DEPTH OF SNOW (inches)



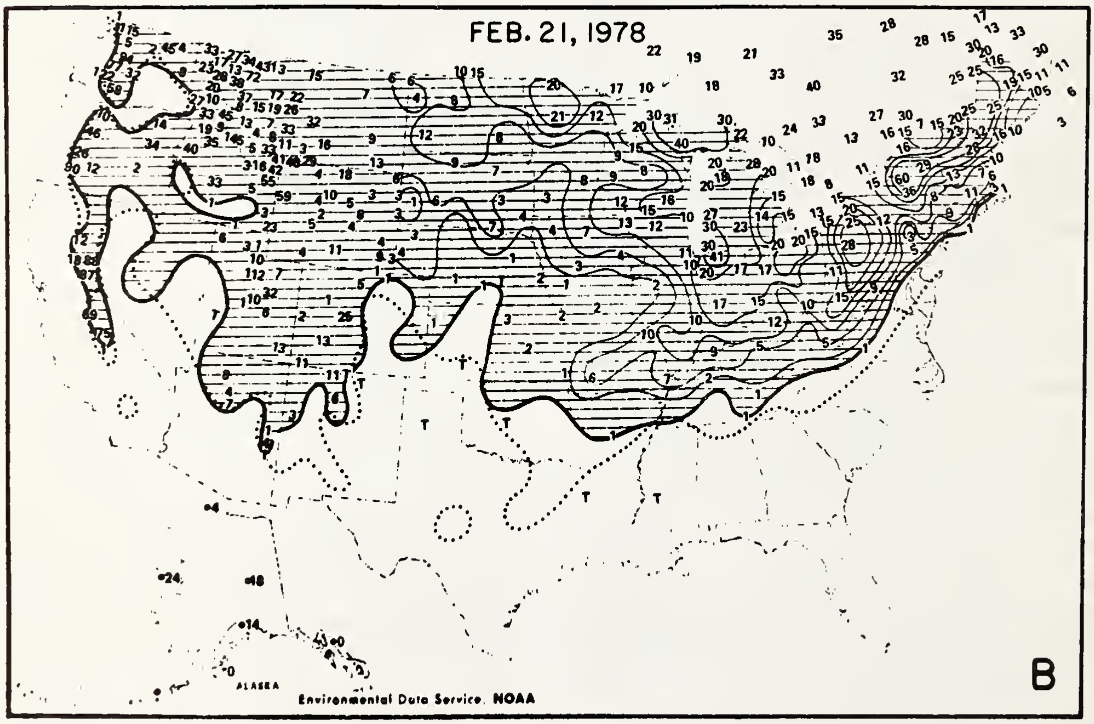


Figure 4.--Depth of snow (inches) on: (A) January 30, 1978, and (B) February 21, 1978. (The dotted line represents extent of snow cover the previous week.) From Weekly Weather and Crop Bulletin, U.S. Departments of Commerce and Agriculture

SPRING 1978

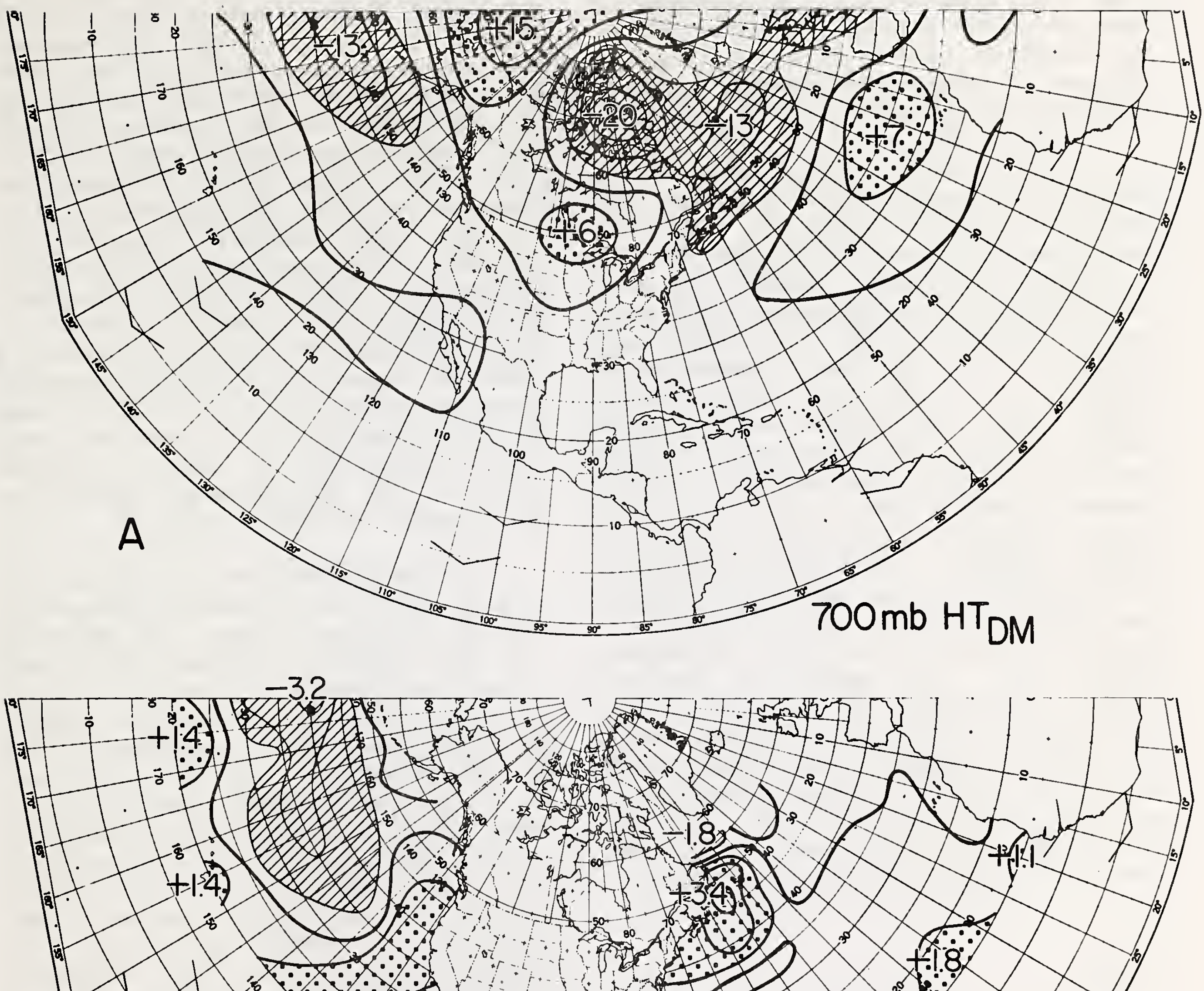


Figure 5.--Mean distribution of: (A) 700 mb height anomaly (feet/10), and (B) sea-surface temperature anomaly (°F) in spring 1978.

snow fields maintaining low temperatures in the invading arctic air mass. As the season advanced, however, the southward penetration of arctic air was gradually lessened as the hemispheric upper westerly airflow flattened and as the westerly axis moved north from its extreme southward displacement in mid-March (Wagner 1979a).

In the Atlantic sector, abnormally strong storm activity continued off the American eastern seaboard, fed by injections of arctic air and by the favorable baroclinic contrast between the refrigerated continental air mass and the offshore ocean.(See Dickson and Namias 1976.) In the seasonal mean (Fig. 5A), the principal low-pressure anomaly cell lay farther north than in winter, forming a pan-Atlantic trough from the Canadian Maritimes to northwestern Europe, and with a second center extending up the Davis Strait to Baffin Island. The storm activity associated with these connected troughs was reflected in an extension of sea-surface cooling south of Greenland where core SST anomalies reached $-1.8^{\circ}F$. Off the American coast the intensification of the persistent warming south of Newfoundland (from $+2.2^{\circ}F$ anomaly in winter to $+3.4^{\circ}F$ anomaly in spring) appeared at variance with the prevailing circulation and may not have been real (Dickson and Namias 1979b).

Summer

The continued evolution of the 700 mb height anomaly field from spring to summer led to a hemispheric circulation pattern that was essentially the reverse of that which had prevailed in the preceding winter (Fig. 6A). Because of this, certain well-entrenched features of the winter SST field which had persisted into spring began to show signs of demolition during summer (Fig. 6B).

In place of the long-established trough south of the Aleutians, an anomalously strong ridge (+70 ft) now extended from Japan to western Canada, resulting in a weakening and fragmentation of the cold water belt in the northern North Pacific through the relative change towards less cloudy skies, dry subsiding air, and surface water convergence. Only at the Canadian west coast itself did new cooling centers arise as the anomalous northerly airflow around the east flank of the Pacific ridge generated conditions compatible with an increased heat exchange and augmented coastal upwelling. This same anomalous northerly airflow also brought about a southward retraction of the preexisting warmth in the southeastern Pacific, though a localized warm center ($+2.5^{\circ}F$ anomaly) remained close to an isolated ridge over Baja California. (In June this ridge represented an extreme pressure departure of 3.5 standard deviations from normal; Taubensee 1979a.)

Over North America the 700 mb circulation was also in marked contrast to that of previous seasons. An extensive and (for summer) extremely deep mean trough over northern Canada (-200 ft, or 3 standard deviations from normal) maintained the cool temperatures over the northern part of the continent, while a zonal ridge farther south brought record or near-record warmth to the southern States. Frontal activity was frequent in the zone of greatest north-south temperature contrast. More generally, this deep polar low, surrounded by a chain of northward-displaced ridges over both oceans and the intervening continent, gave rise to strong upper westerlies at high latitudes, most notably in June when the polar westerly index (55°-$70^{\circ}N$) over the western half of the Northern Hemisphere reached a 30-year record value of 4.7 m/s, 2.5 m/s stronger than normal (Taubensee 1979a).

In the Atlantic sector (as with the Pacific), the full ocean ridge over the northern North Atlantic removed much of the preexistent cooling from the Laborador Sea to Europe. South of Newfoundland, the apparent ocean warm-

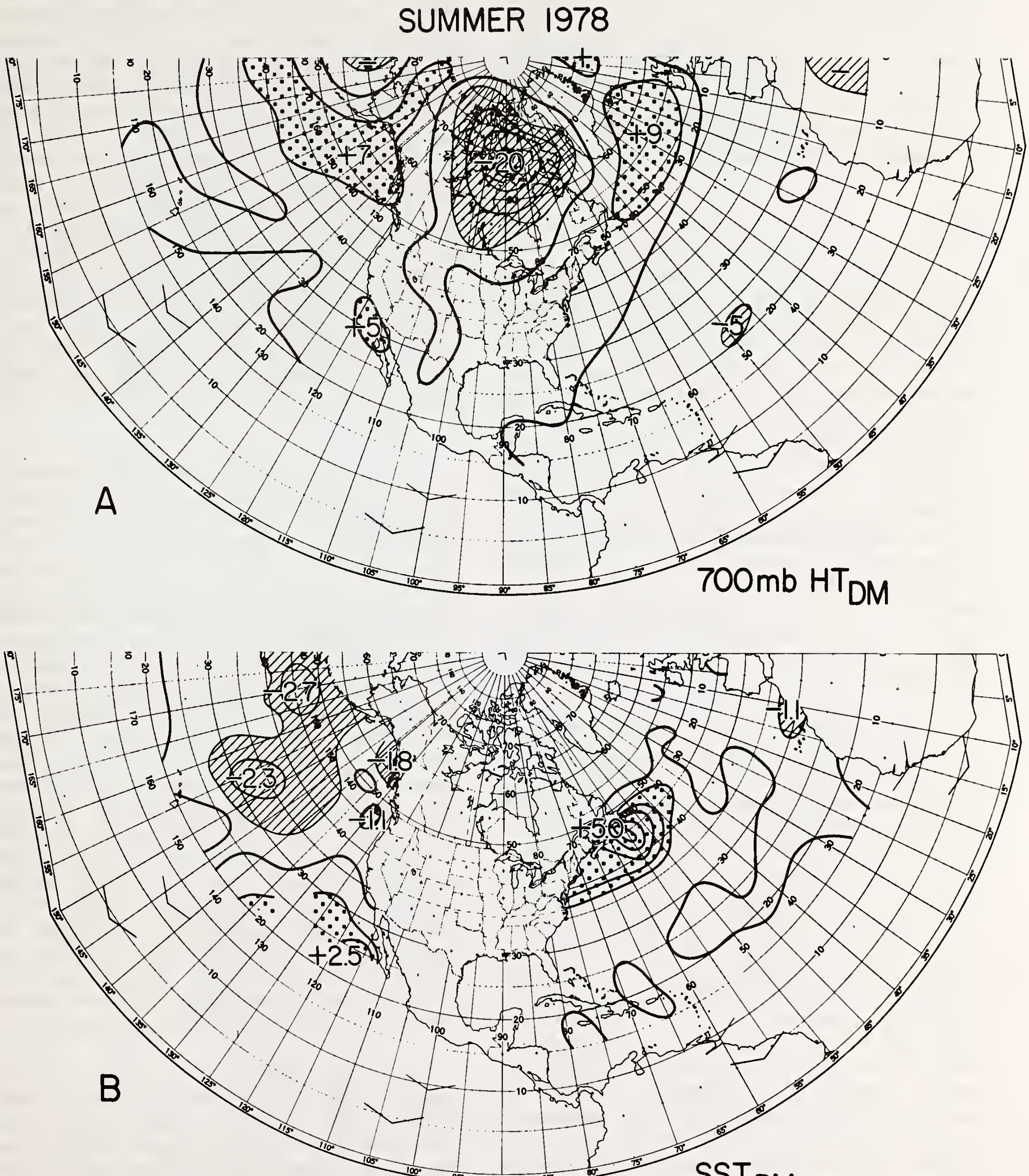


Figure 6.--Mean distribution of: (A) 700 mb height anomaly (feet/10), and (B) sea-surface temperature anomaly (^{o}F) in summer 1978.

ing continued under an anomalous southerly airflow with maximum SST anomalies of +5.0°F at its core. Farther south, a zonal band of slightly colder than normal surface water from 15°-30°N helped to suppress tropical storm activity until late in the season, continuing the trend of recent years (Taubensee 1979a; Wagner 1979b).

Fall

Though fall was characterized by great unsteadiness in its circulation from month to month, the mean distribution of 700 mb height anomaly for the season as a whole (Fig. 7A) can still be recognized as an outgrowth of the summer circulation, though with greatly amplified centers of action. An intense polar low (-210 ft, 3 standard deviations from normal) continued to dominate high latitudes and continued to be surrounded at lower latitudes by anomalously strong and northward-displaced ridges with centers in the Gulf of Alaska, the eastern United States, and the eastern Atlantic (the latter also more than 3 standard deviations from normal).

The intensification of the northeastern Pacific ridge--occurring chiefly in the late fall--was perhaps a predictable development; Namias (1976) demonstrated from a 26-year time series of data that in the transition from warm to cold seasons, positive pressure anomalies frequently develop in the northeastern Pacific in fall at the site of abnormally cold surface water during the antecedent summer. As in the present case, however, the cycle of negative feedback is then completed with the destruction of the cold water zone under the anomalous anticyclonic regime (Namias, in press). Figure 7B shows that in fall 1978 the long-sustained surface cooling which had dominated the northern North Pacific in virtually every season of recent years was now almost completely eradicated. Cooling continued to develop, however, in a narrow coastal strip bordering the Gulf of Alaska, where the northerly anomalous airflow around the Pacific anticyclone continued to favor strong coastal upwelling. A late season troughing tendency farther south over southern California and Mexico, only faintly shown in the seasonal mean, completed the destruction of the less well-entrenched warmth in the southeastern Pacific, and subnormal ocean temperatures even developed locally off Baja California. This development of an upper level trough in the western or southwestern United States, coupled with intensified ridging over eastern North America (Fig. 7A), are both expected downstream responses under the type of summer-fall mechanism which Namias described. (See Namias 1976, p. 1115.)

In the Atlantic sector, Figure 7B shows two major changes in SST anomaly distribution from summer to fall. First, the northwestern Atlantic cooled dramatically under the strong northwesterly flow between the deep polar trough and the eastern American ridge, both of which extended over the ocean. The preexisting area of warm surface temperatures near Newfoundland cooled from a +5.0°F to a +3.1°F anomaly and retracted towards the coast, while farther to the north and east, the near normal ocean temperatures of summer were cooled by an equivalent amount, developing core anomalies of -1.6°F. In the eastern Atlantic, the second main development was the rapid spread of ocean warming along a narrow tongue extending from northwestern Africa to the British Isles (core anomalies of +1.8°F), the result of strong and persistent warm southerly airflow around the upper level ridge in this area.

In the Atlantic, as in most of the western half of the Northern Hemisphere, the axis of upper westerlies was intense and displaced far to the north of normal, with peak upper wind speeds (5 to 8 m/s above normal in September; Taubensee 1979b) developing between Britain and Greenland through coupling between a polar trough and an

FALL 1978

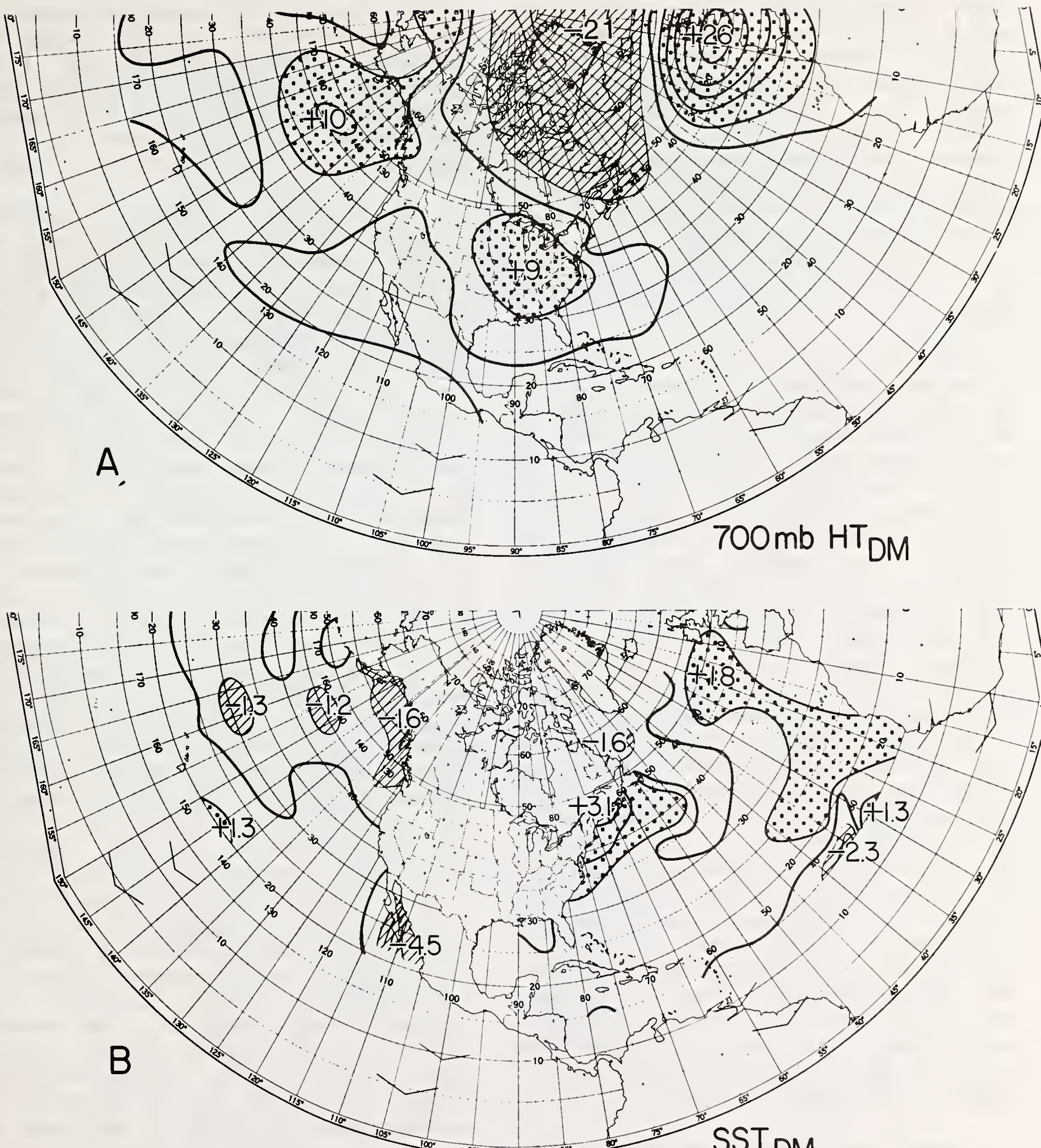


Figure 7.--Mean distribution of: (A) 700 mb height anomaly (feet/10), and (B) sea-surface temperature anomaly (^{O}F) in fall 1978.

eastern Atlantic ridge that were both 3 standard deviations from normal for the season. With the strong subtropical ridges also displaced to the north of normal over both oceans, the subtropical westerlies aloft continued their recent trend of weakness. As is normal in this situation (Wagner 1979c), tropical storm activity was greater than normal, with the increase being especially pronounced over the Atlantic, where tropical activity had hitherto been markedly weak.

Winter

During winter 1978-79, the anomalous eastern Pacific ridge continued to spread and intensify across much of the northern North Pacific (Fig. 8A) in marked contrast to the record-breaking cyclonic activity which had occupied this sector during the previous two winters. Initially, in December, its continued development from fall was aided by intense upstream cyclonic activity over favorable thermal fields near Kamchatka. Later in the season it received support in the north from the westward retrogression of an intense high latitude blocking ridge which had formed over Greenland in December (from the preexisting European ridge) and which had moved successively to the Canadian Arctic and the Bering Sea in January and February. In the seasonal mean (Fig. 8A), this westward migration is smeared into a single band of abnormally high pressure stretching from the western Pacific to Scandinavia. The 700 mb polar westerlies at 55°-70°N were correspondingly weak throughout the winter, with western hemispheric wind speed anomalies of -3.2 m/s in December and -2.4 m/s in January (Taubensee 1979c; Wagner 1979d).

Reverting to the North Pacific, the zone of influence of the Pacific ridge was well shown by the change in the total number of winter storms between winter 1977-78 and winter 1978-79 (Fig. 9). The overall change amounts to a decrease of more than 10 storms per season near the central location of the ridge (155°-165°W at 40°N). As a result, persistent surface cooling gave way to anomalous warmth in the Gulf of Alaska (+2.0°F), though the northerly airflow around the ridge continued to boost upwelling and intensify cooling (to a -2.8°F anomaly) off Baja California from fall to winter.

Over North America, the key feature of winter 1978-79 was the extent, severity, and persistence of extreme cold conditions originating in the west during December under northerly outbreaks from the Pacific ridge, but later spreading to cover most of the United States in January and February. Unlike the preceding winters, the center of cooling lay in the Midwest rather than in the East, but the baroclinic zone at the Atlantic seaboard was nevertheless relatively strong. Partly through this effect, but mainly through the presence of a deep pan-Atlantic trough aloft (-290 ft), there was a general increase in total storm activity between eastern North America and the southwestern coast of Europe (Fig. 9). In this zone the short-lived warming in the eastern Atlantic was almost eradicated during winter, and extensive surface cooling developed beneath the main trough in the mid-Atlantic. To the north of this cell, the domain of high latitude blocking is marked in Figure 9 by a narrow zone of decreased storm frequency from southern Greenland to Scandinavia, but a fierce westerly drive between the Greenland ridge and the Atlantic trough precluded any extensive ocean warming (upper westerlies in this sector averaged 12 m/s above normal speeds during December; Taubensee 1979c). In the western and southwestern Atlantic, a new zone of warmth curving in from the southeast (Fig. 8B) coalesced with the preexisting warm zone south of Newfoundland. Although forming a continuous strip of above normal ocean temperatures, it is clear that the northern part, south of Newfoundland, represents

WINTER 1979

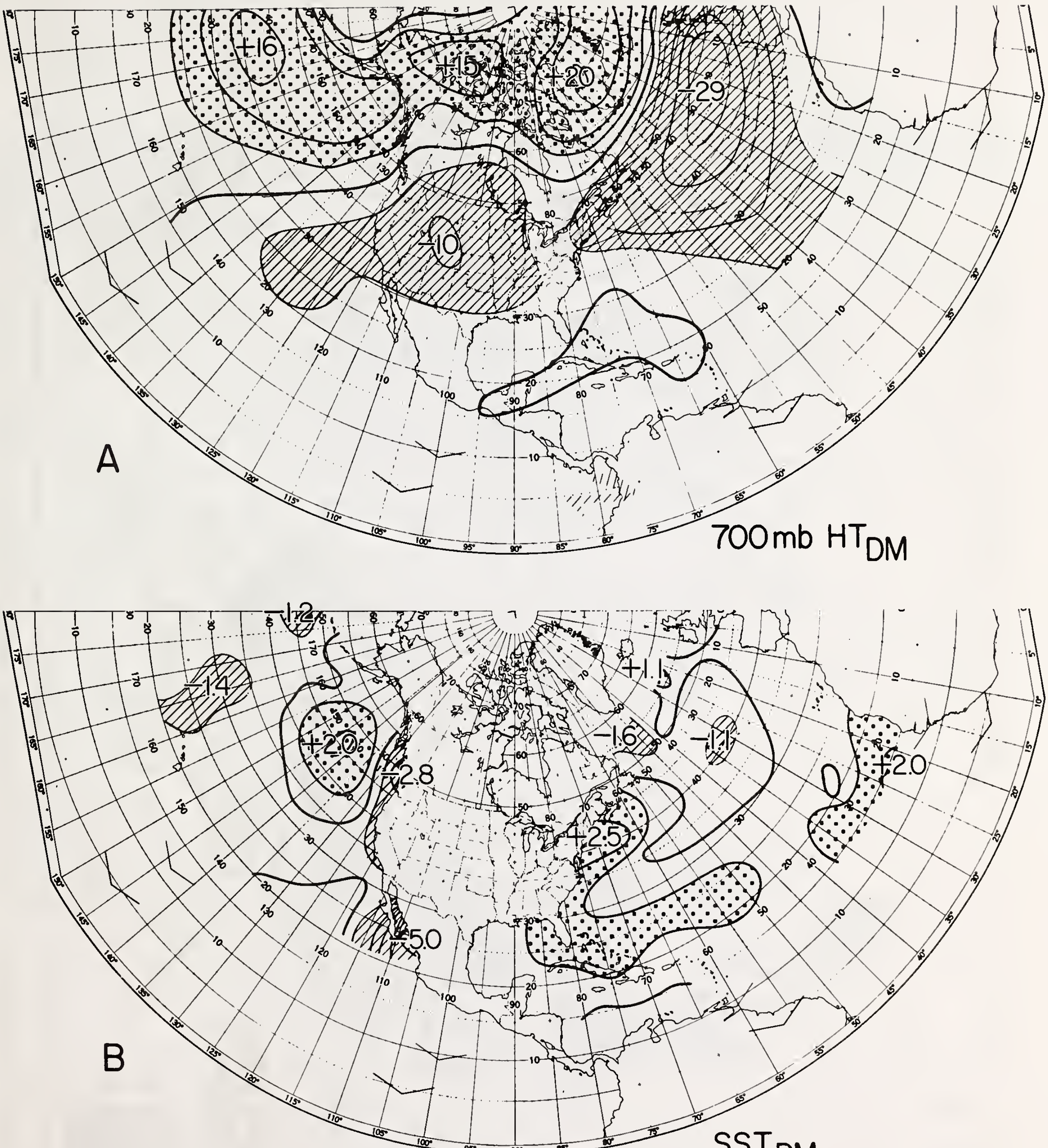


Figure 8.--Mean distribution of: (A) 700 mb height anomaly (feet/10), and (B) sea-surface temperature anomaly (^{o}F) in winter 1979.

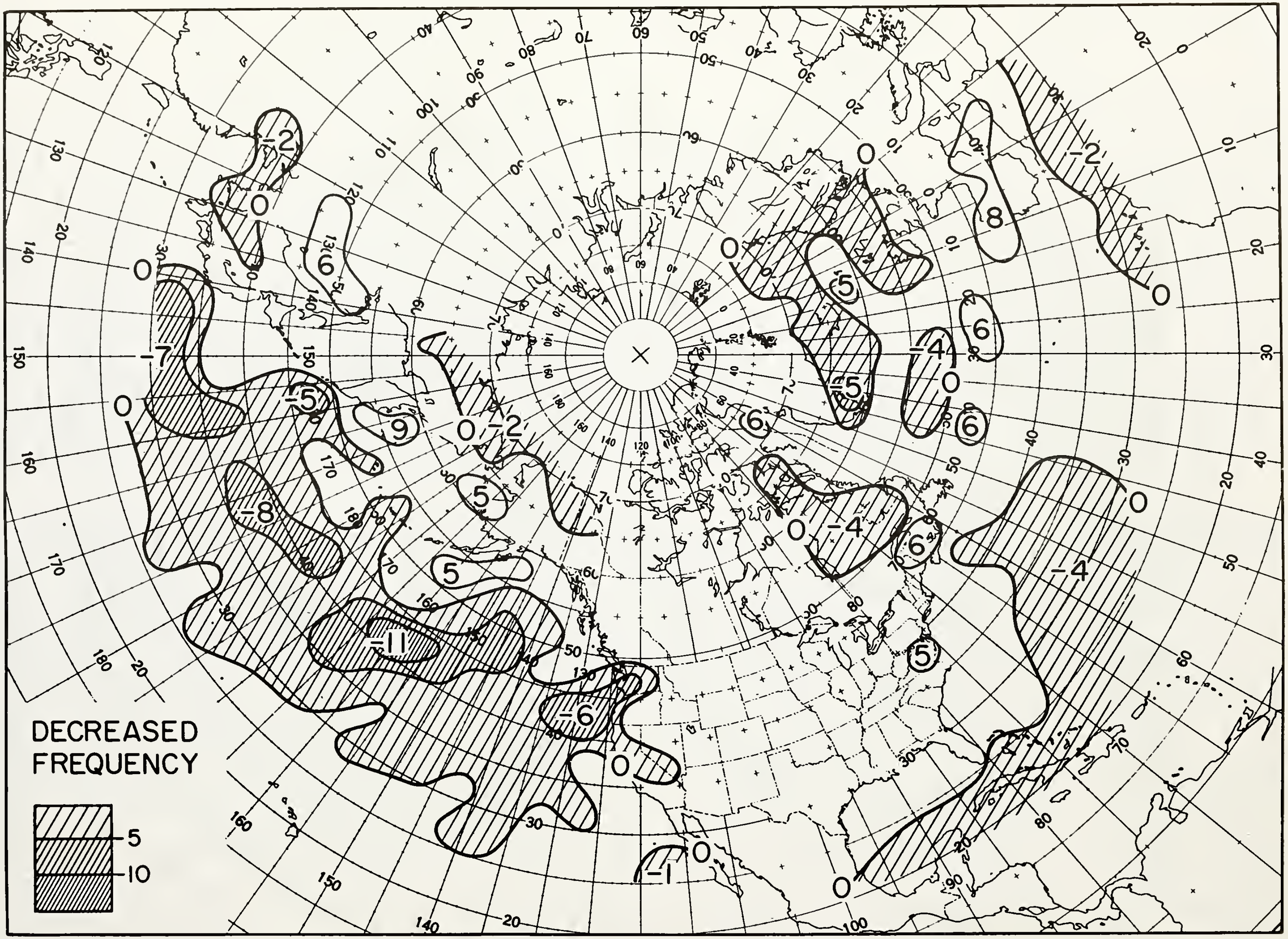


Figure 9.--Change in total storms per season between winter 1977-78 and winter 1978-79. Areas of decreased storm frequency are shaded. Based on monthly storm track charts in Mariners Weather Log, U.S. Dep. Commer.

merely a retraction of antecedent warmth, while the southern part represents actual winter warming beneath the mild southerly airflow to the southwest of the Atlantic trough.

ACKNOWLEDGMENTS

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Wagner, A. J. 1979c. Weather and circulation of October 1978, mostly dry with a warm West and cold East. Mon. Weather Rev. 107:96-102.

Wagner, A. J. 1979d. Weather and circulation of January 1979, widespread record cold with heavy snowfall in the Midwest. Mon. Weather Rev. 107:499-506.

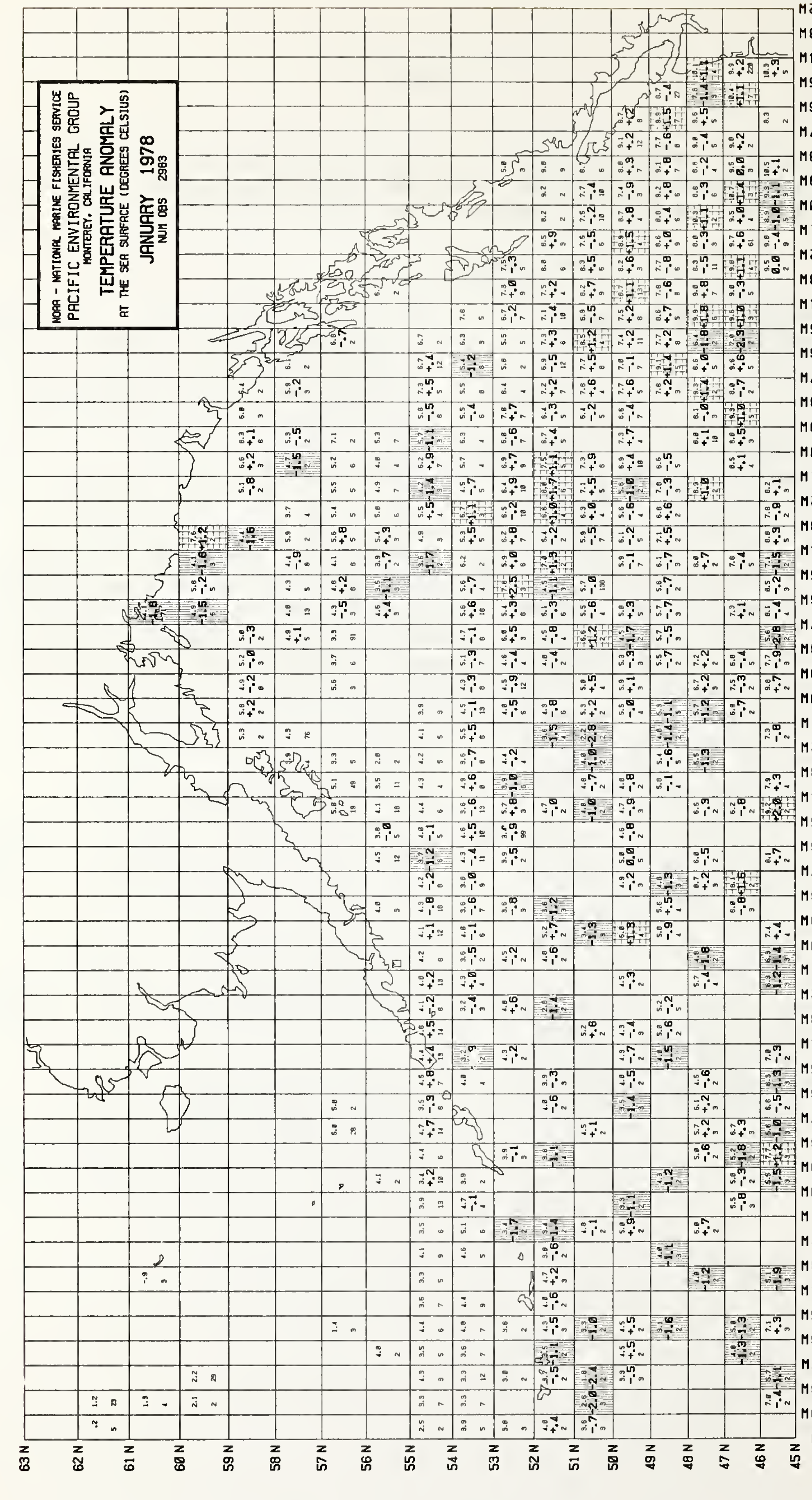
APPENDIX

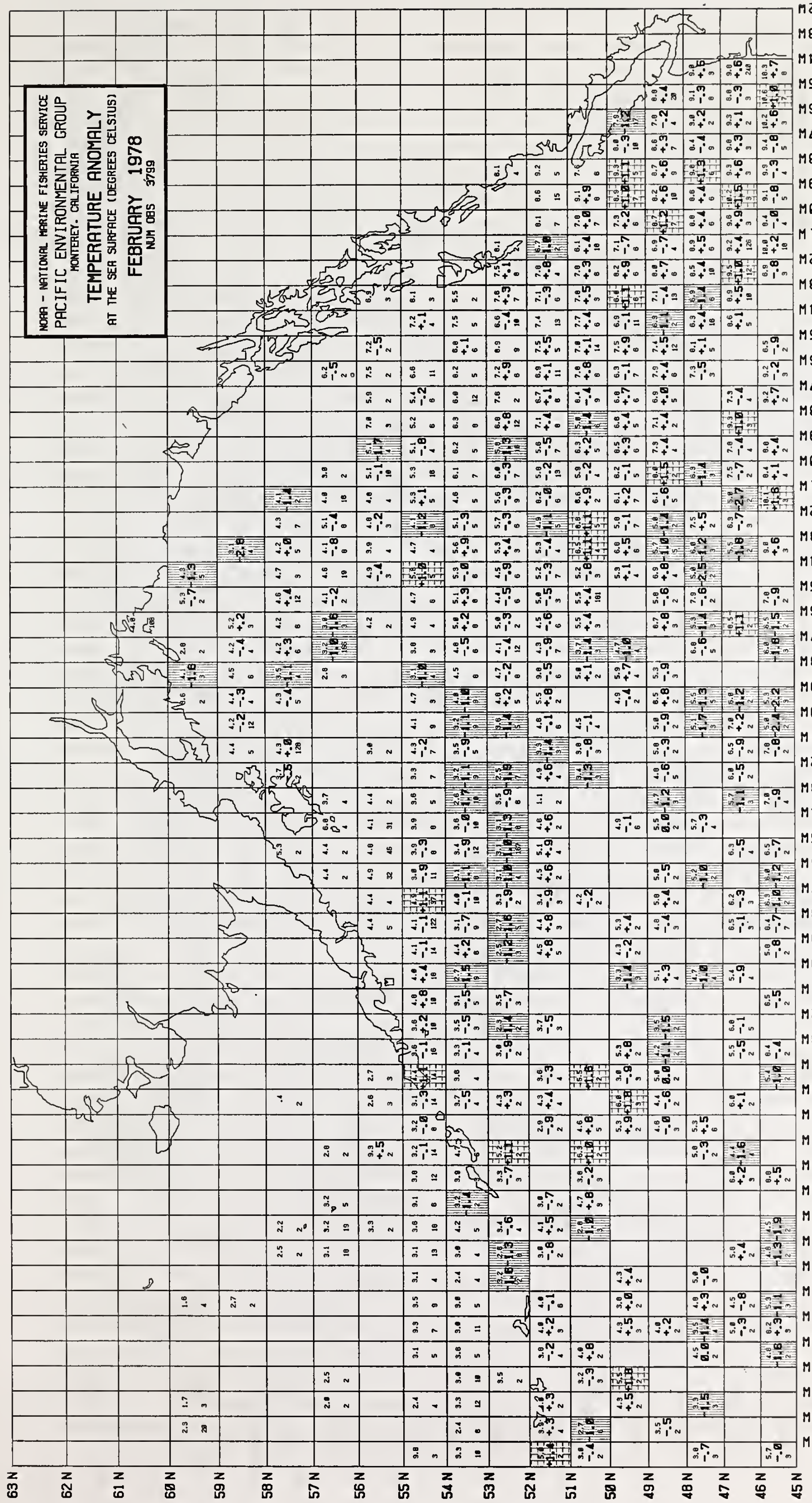
The following maps present sea-surface temperatures by one-degree squares of latitude and longitude for the 15 months January 1978–March 1979.

They cover the areas of:

the Bering Sea and Gulf of Alaska	(45^{o}-63^{o}N, 122^{o}-180^{o}W),
the Eastern North Pacific	(25^{o}-50^{o}N, 110^{o}-150^{o}W), and
the western North Atlantic and Gulf of Mexico	(20^{o}-46^{o}N, 60^{o}- 99^{o}W).

The upper figure is the average of the reports for that square that month, mostly from merchant ship cooling water intake temperatures; a lone observation is not plotted. The larger, central figure is the departure from the long-term (1948-67) mean; none is plotted if there are fewer than five years' data in the 20-year mean. Anomalies greater than 1^{o}C are shaded. The lower figure is the number of observations received.


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JANUARY 1978
NUM OBS 2983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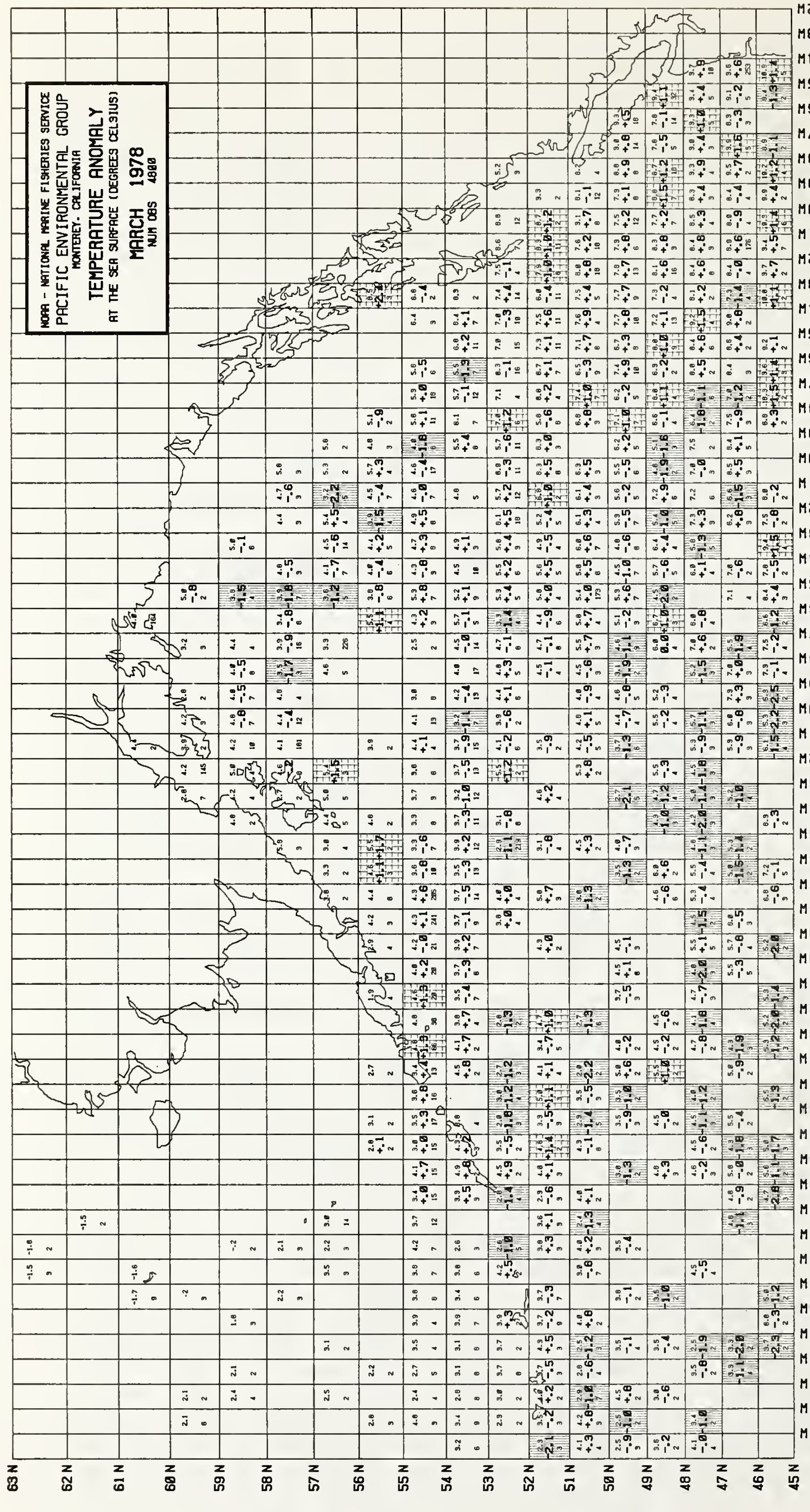
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
FEBRUARY 1978
NUM OBS 3799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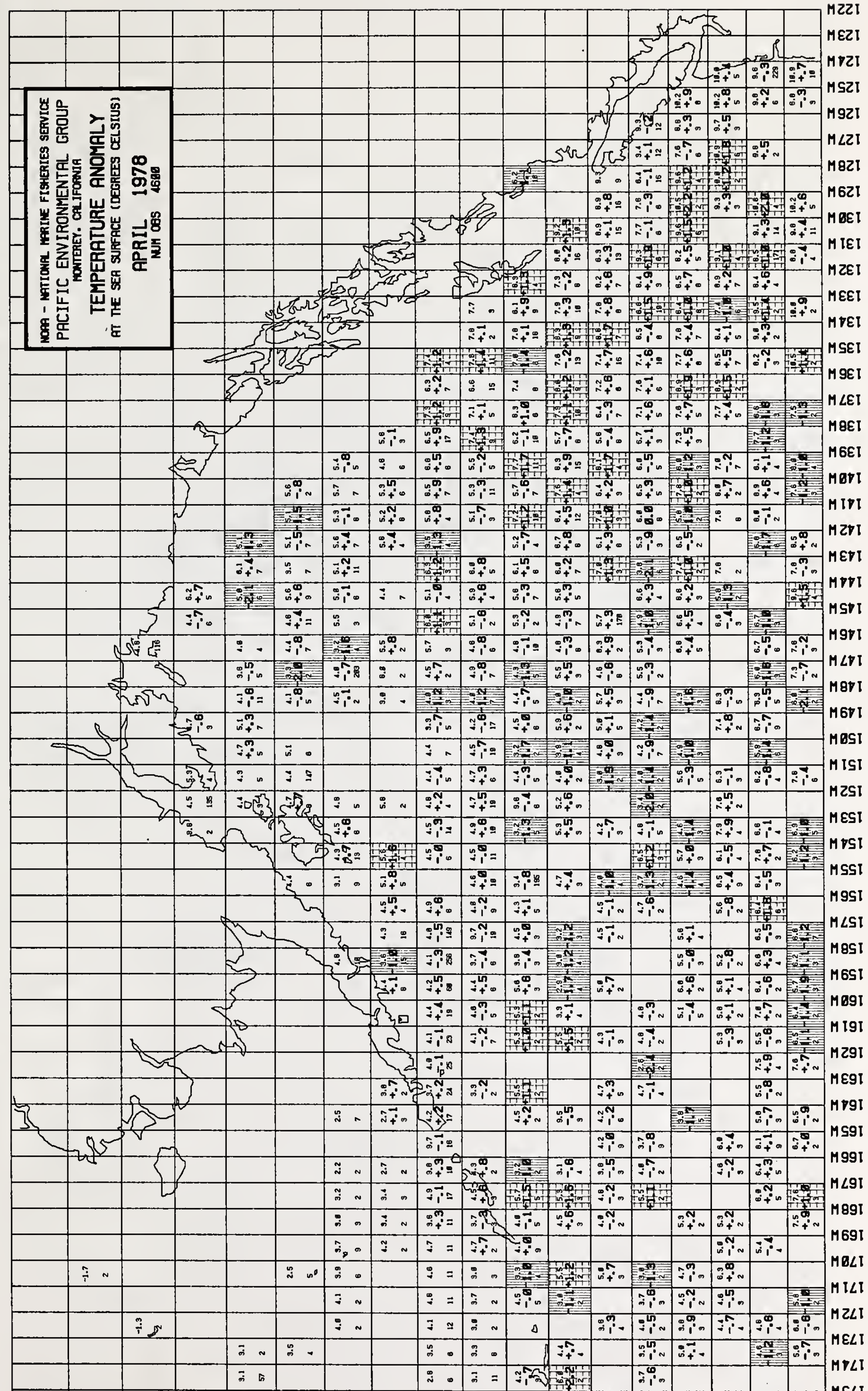
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MARCH 1978
NUM OBS 4800


NOAA - NATIONAL MARINE FISHERIES SERVICE
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MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
APRIL 1978
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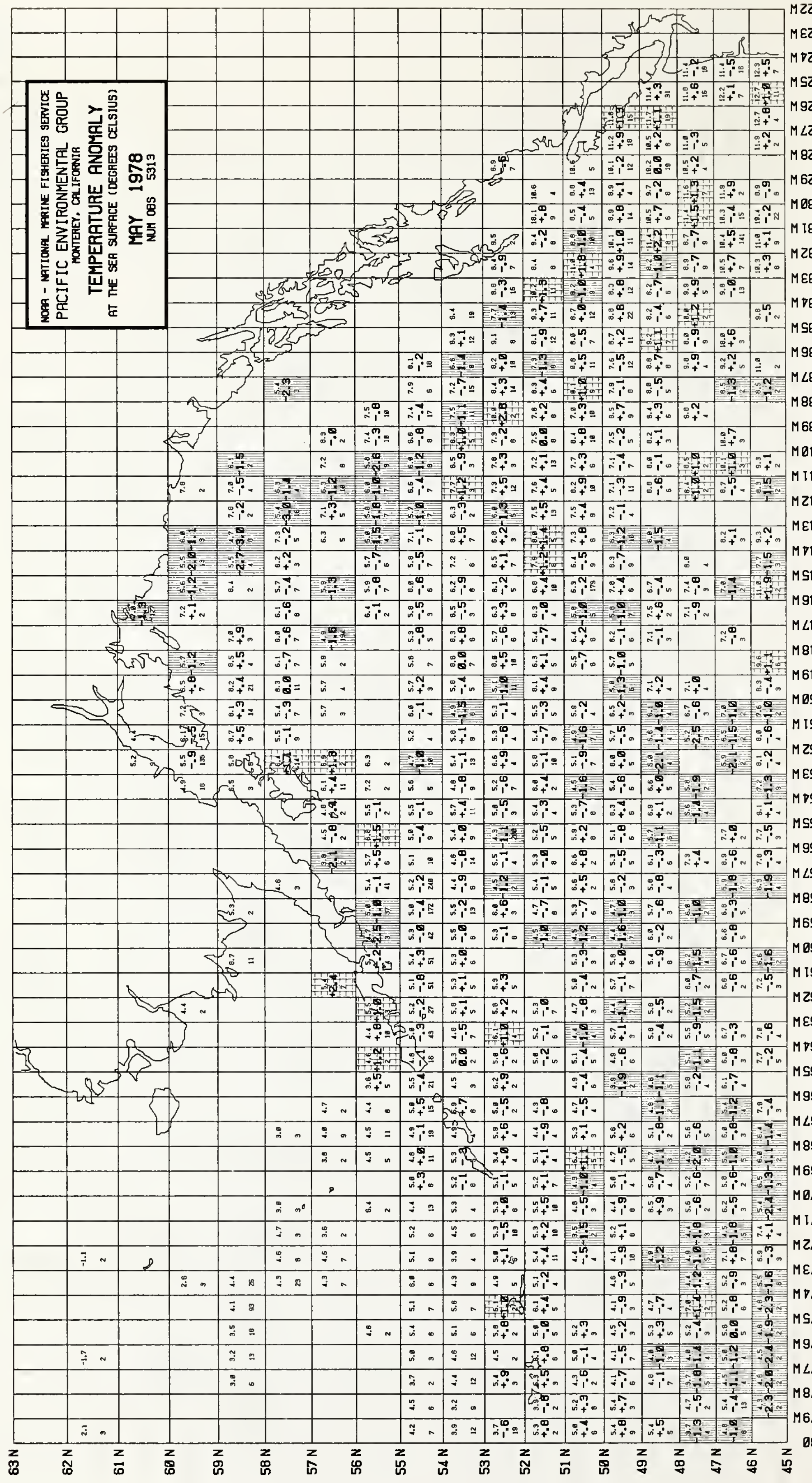
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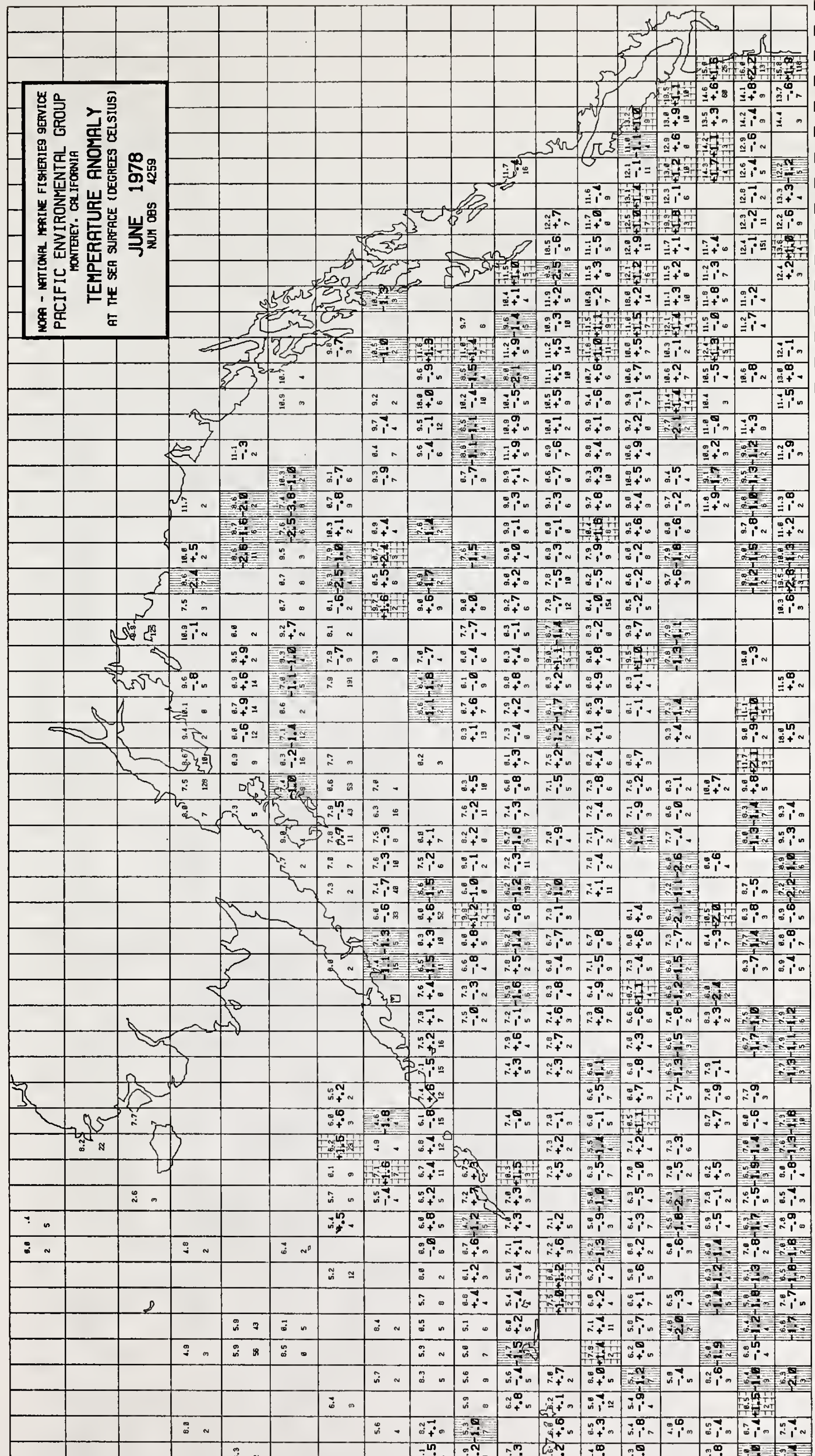
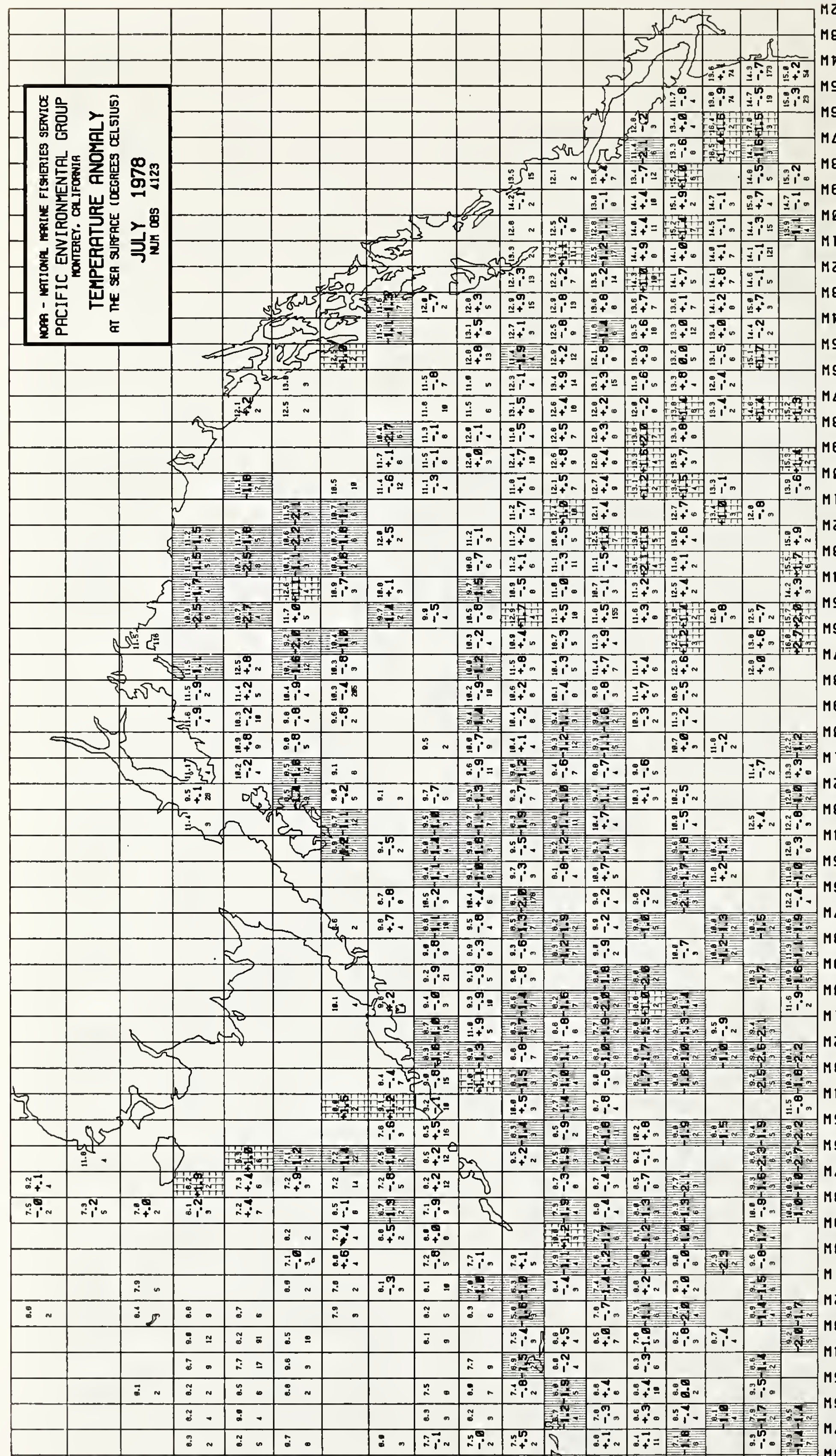
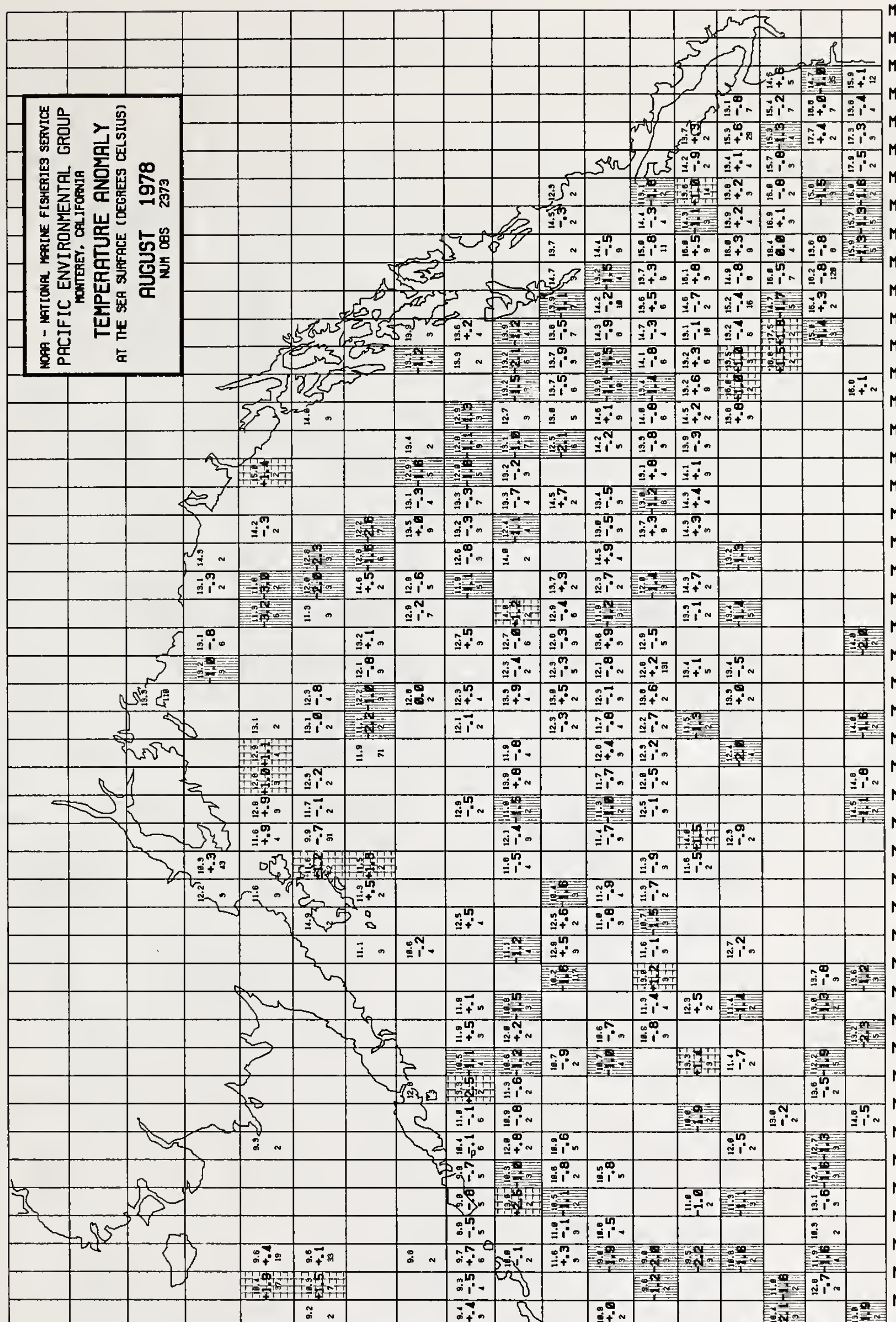
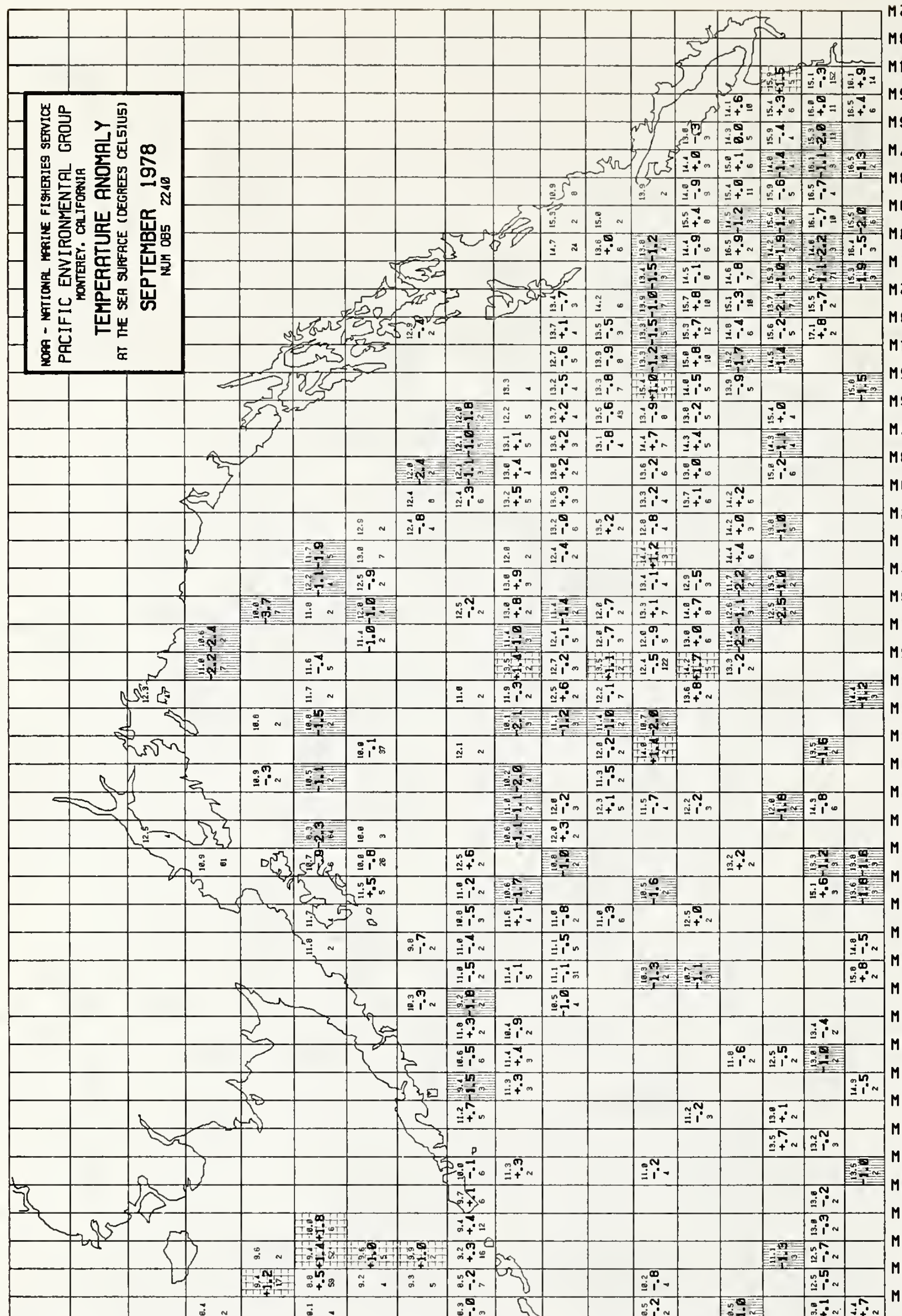
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MAY 1978
NUM OBS 5313

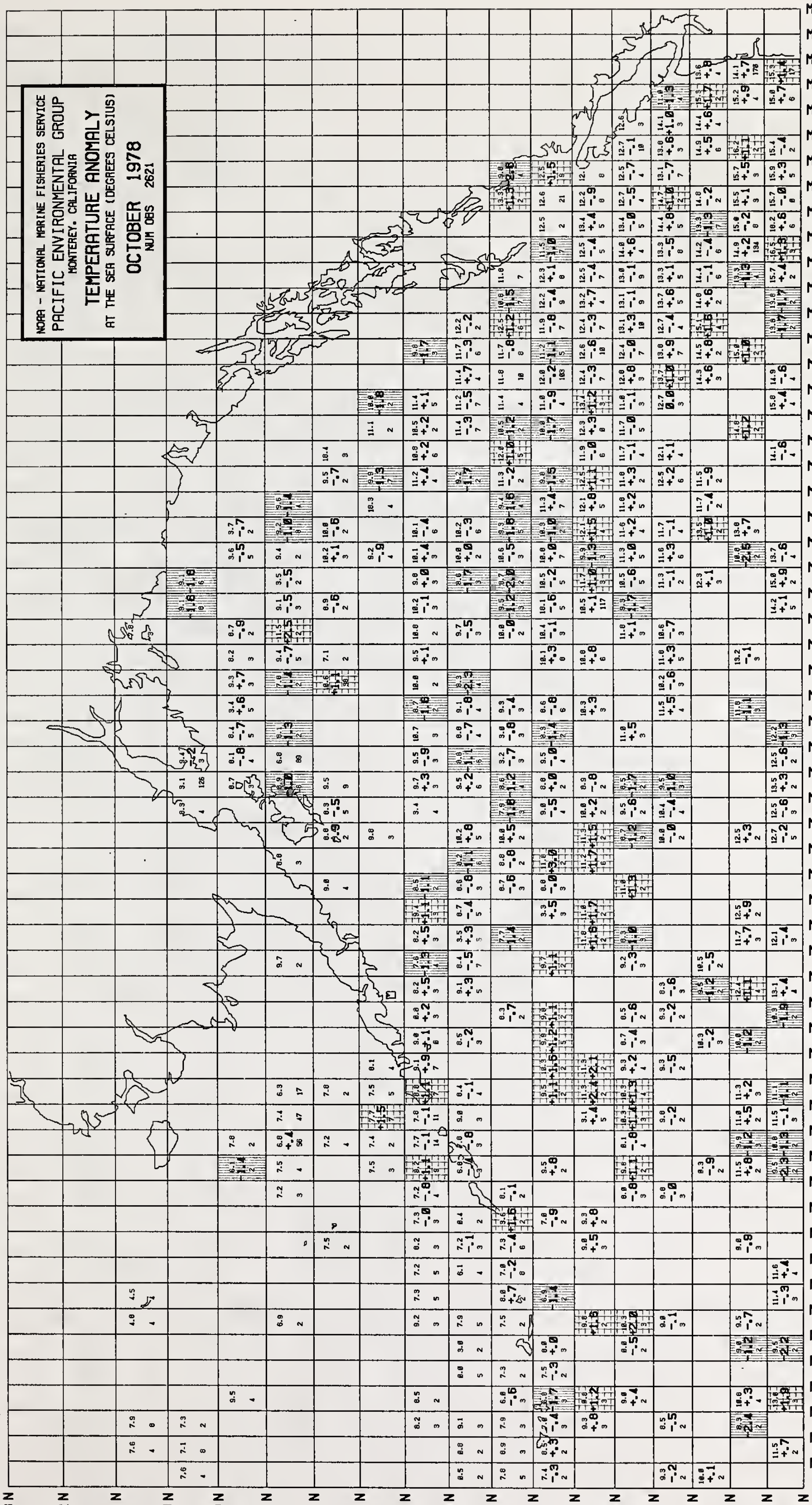


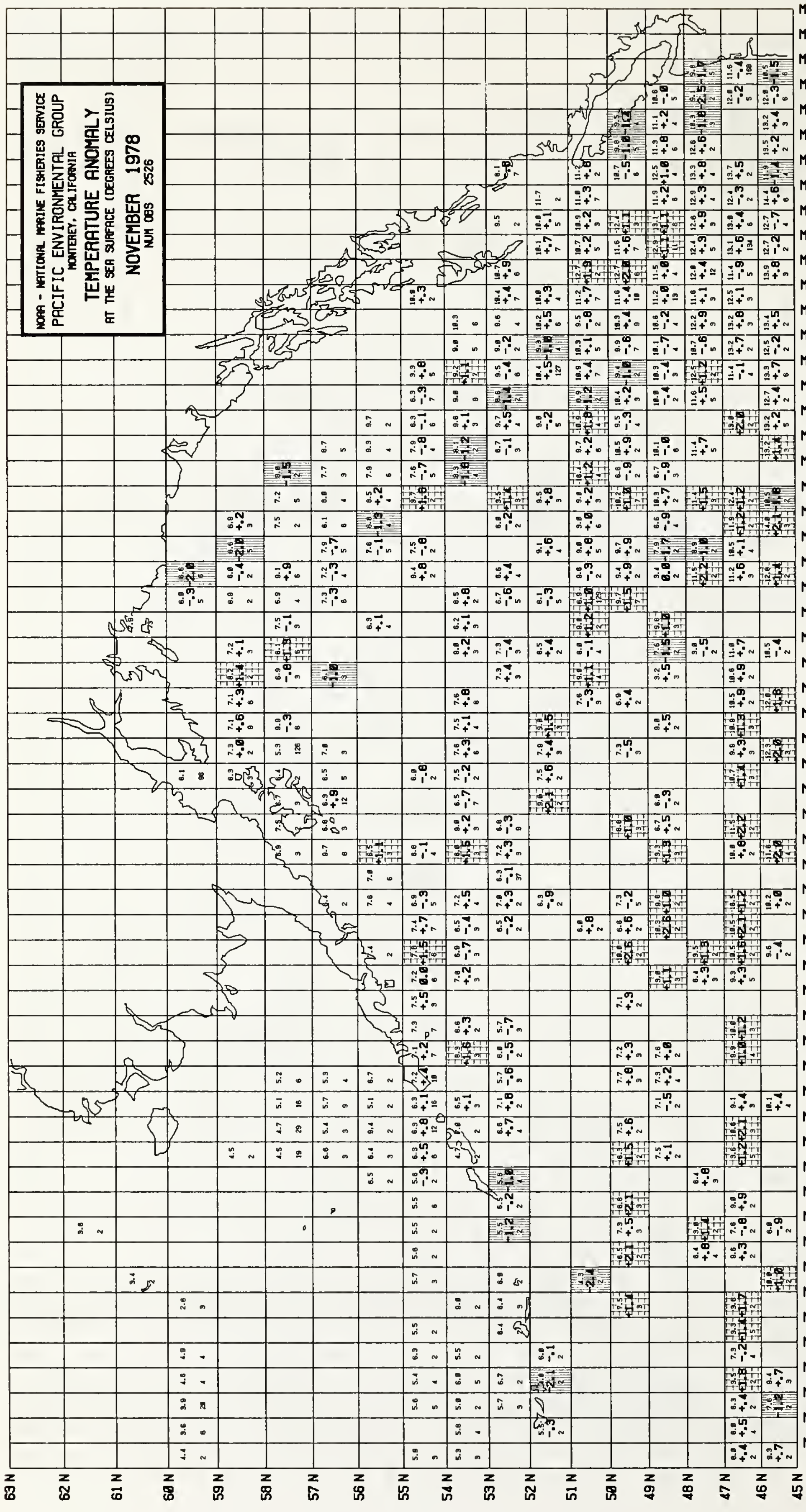
NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JUNE 1978
NUM OBS 4259


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JULY 1978
NUM OBS 4123
63N 62N 61N 60N 59N 58N 57N 56N 55N 54N 53N 52N 51N 50N 49N 48N 47N 46N 45N
180 179W 178W 177W 176W 175W 174W 173W 172W 171W 170W 169W 168W 167W 166W 165W 164W 163W 162W 161W 160W 159W 158W 157W 156W 155W 154W 153W 152W 151W 150W 149W 148W 147W 146W 145W 144W 143W 142W 141W 140W 139W 138W 137W 136W 135W 134W 133W 132W 131W 130W 129W 128W 127W 126W 125W 124W 123W 122W


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
AUGUST 1978
NUM OBS 2373


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
SEPTEMBER 1978
NUM OBS 2240


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
OCTOBER 1978
NUM OBS 2621


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
NOVEMBER 1978
NUM OBS 2526
63 N
62 N
61 N
60 N
59 N
58 N
57 N
56 N
55 N
54 N
53 N
52 N
51 N
50 N
49 N
48 N
47 N
46 N
45 N
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179W
178W
177W
176W
175W
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173W
172W
171W
170W
169W
168W
167W
166W
165W
164W
163W
162W
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138W
137W
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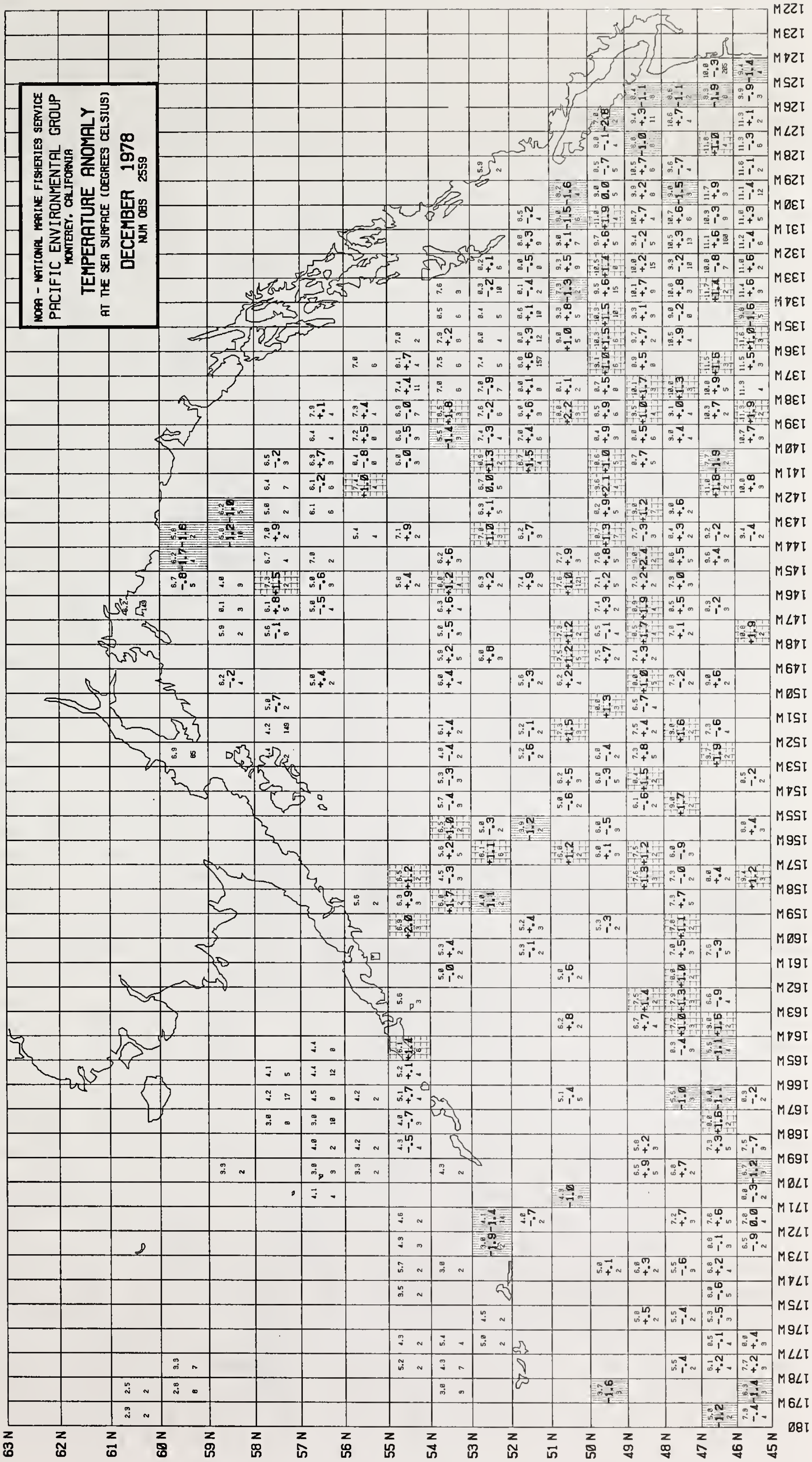
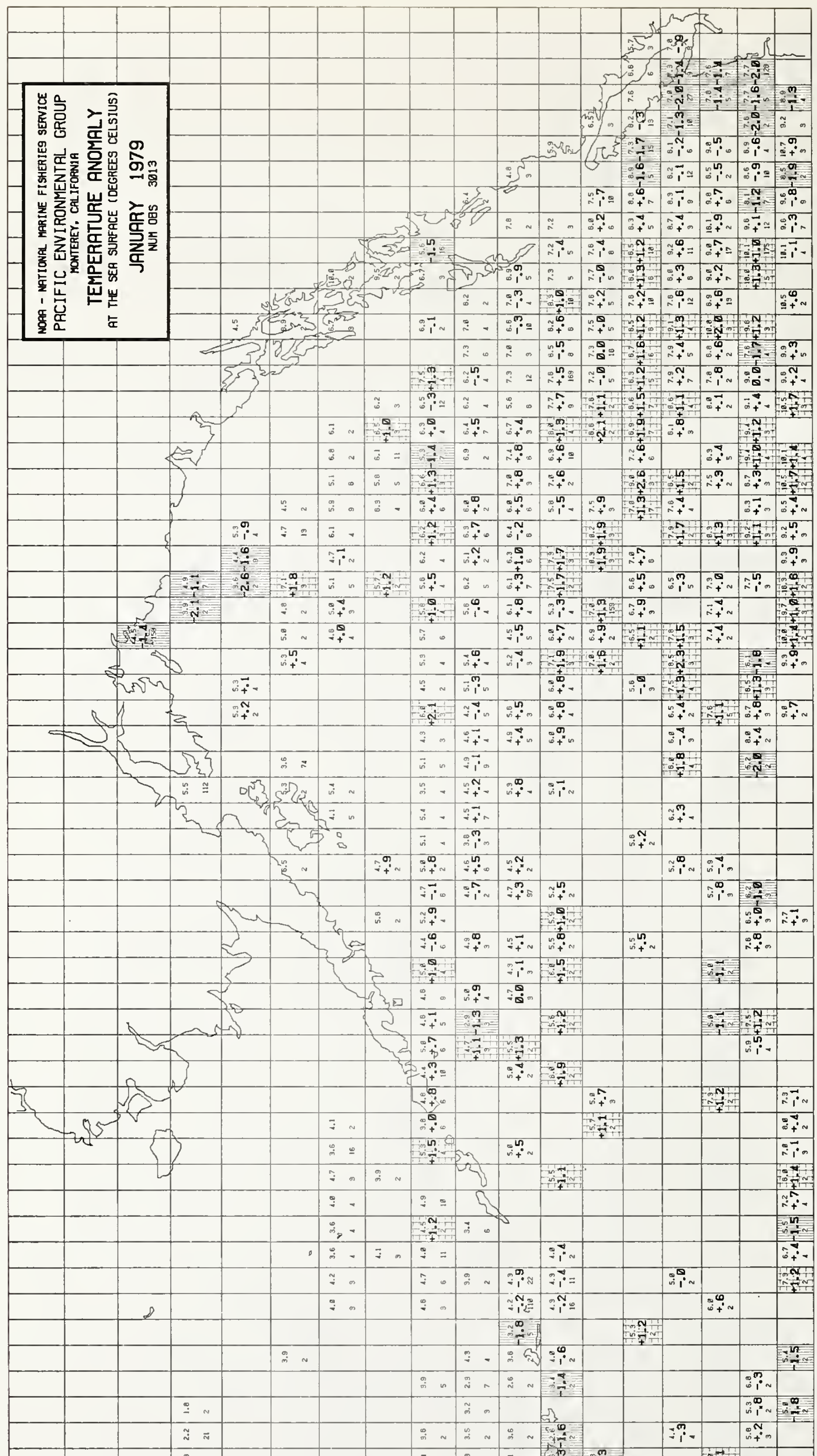
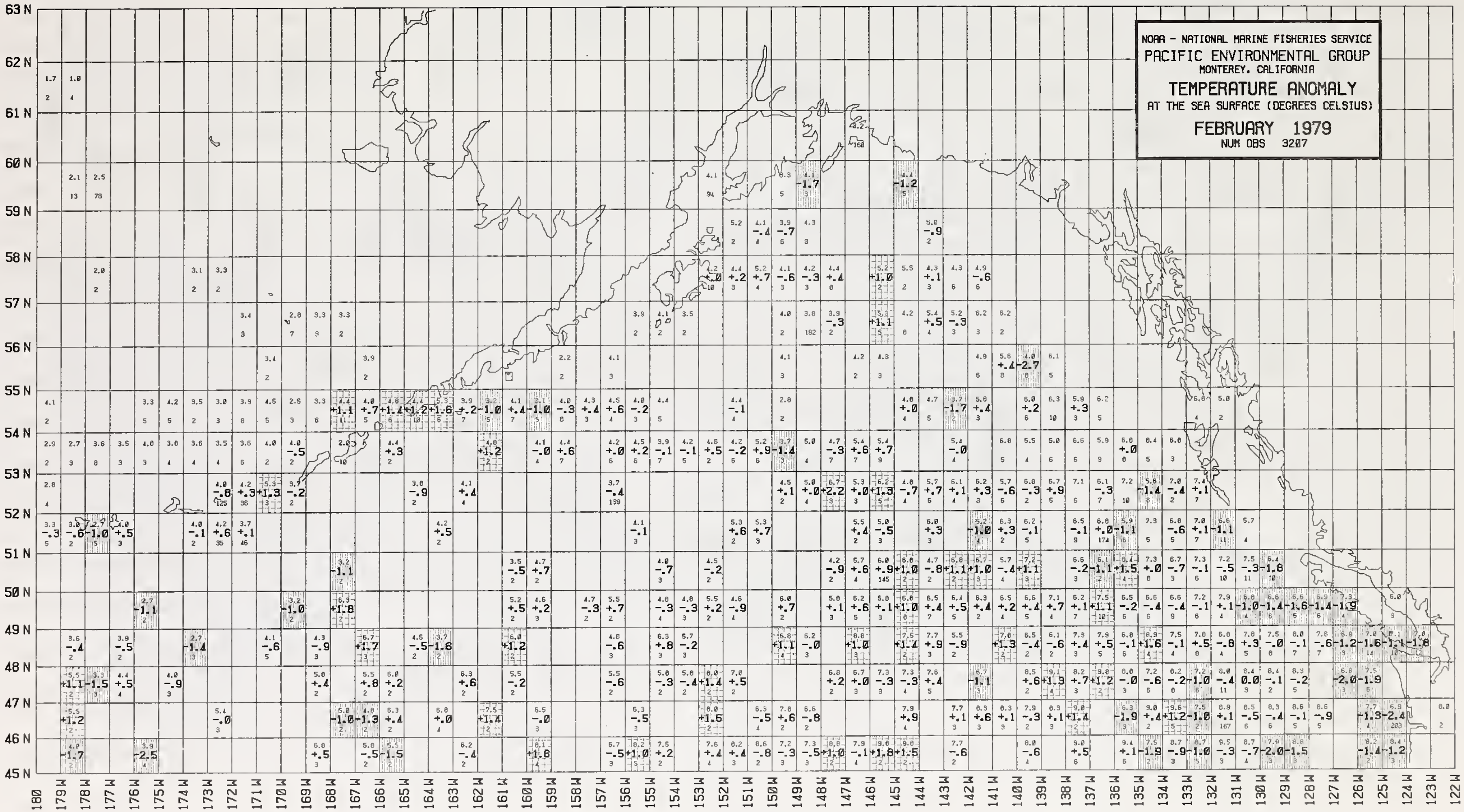
122W


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
DECEMBER 1978
NUM OBS 2559


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JANUARY 1979
NUM OBS 3013


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
FEBRUARY 1979
NUM OBS 3207
63 N
62 N
61 N
60 N
59 N
58 N
57 N
56 N
55 N
54 N
53 N
52 N
51 N
50 N
49 N
48 N
47 N
46 N
45 N
180
179W
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177W
176W
175W
174W
173W
172W
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168W
167W
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165W
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163W
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138W
137W
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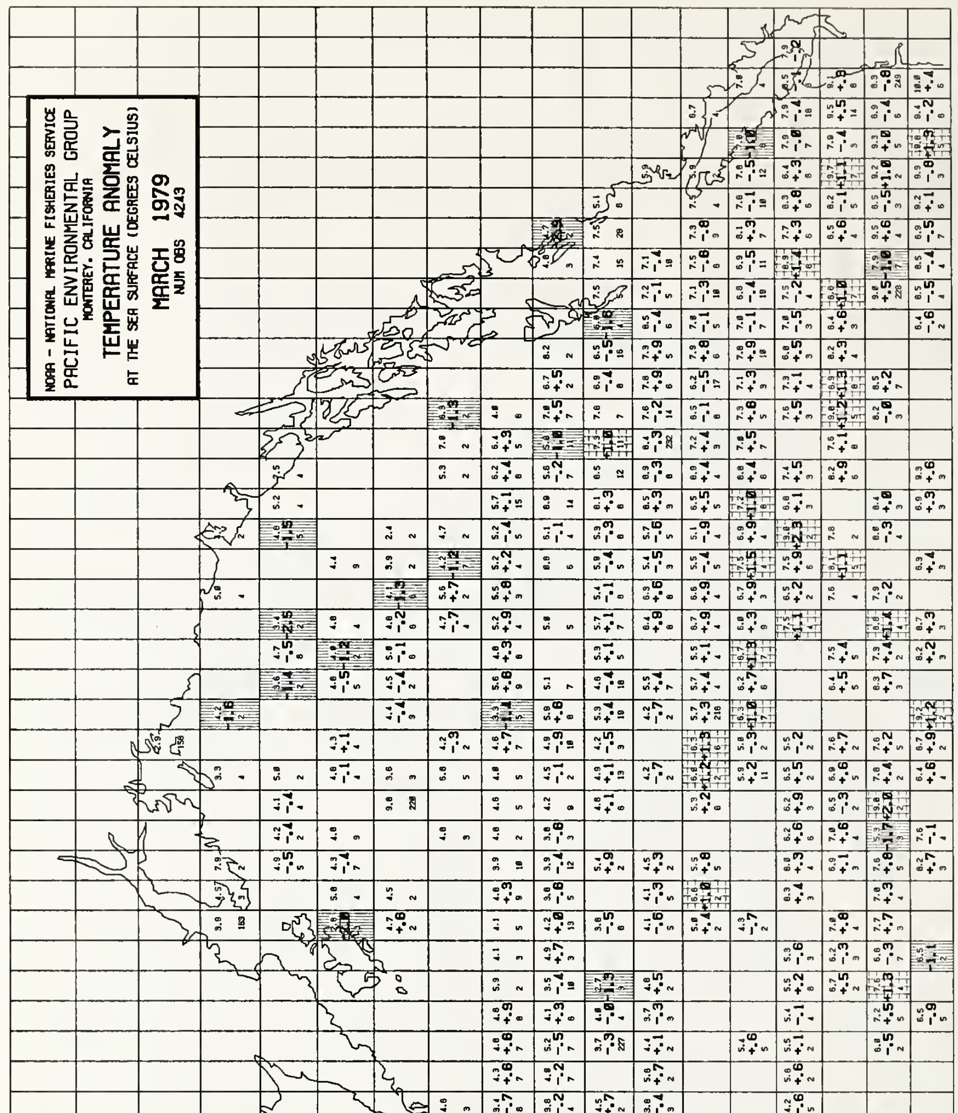
NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MARCH 1979
NUM OBS 4243
63 N
62 N
61 N
60 N
59 N
58 N
57 N
56 N
55 N
54 N
53 N
52 N
51 N
50 N
49 N
48 N
47 N
46 N
45 N
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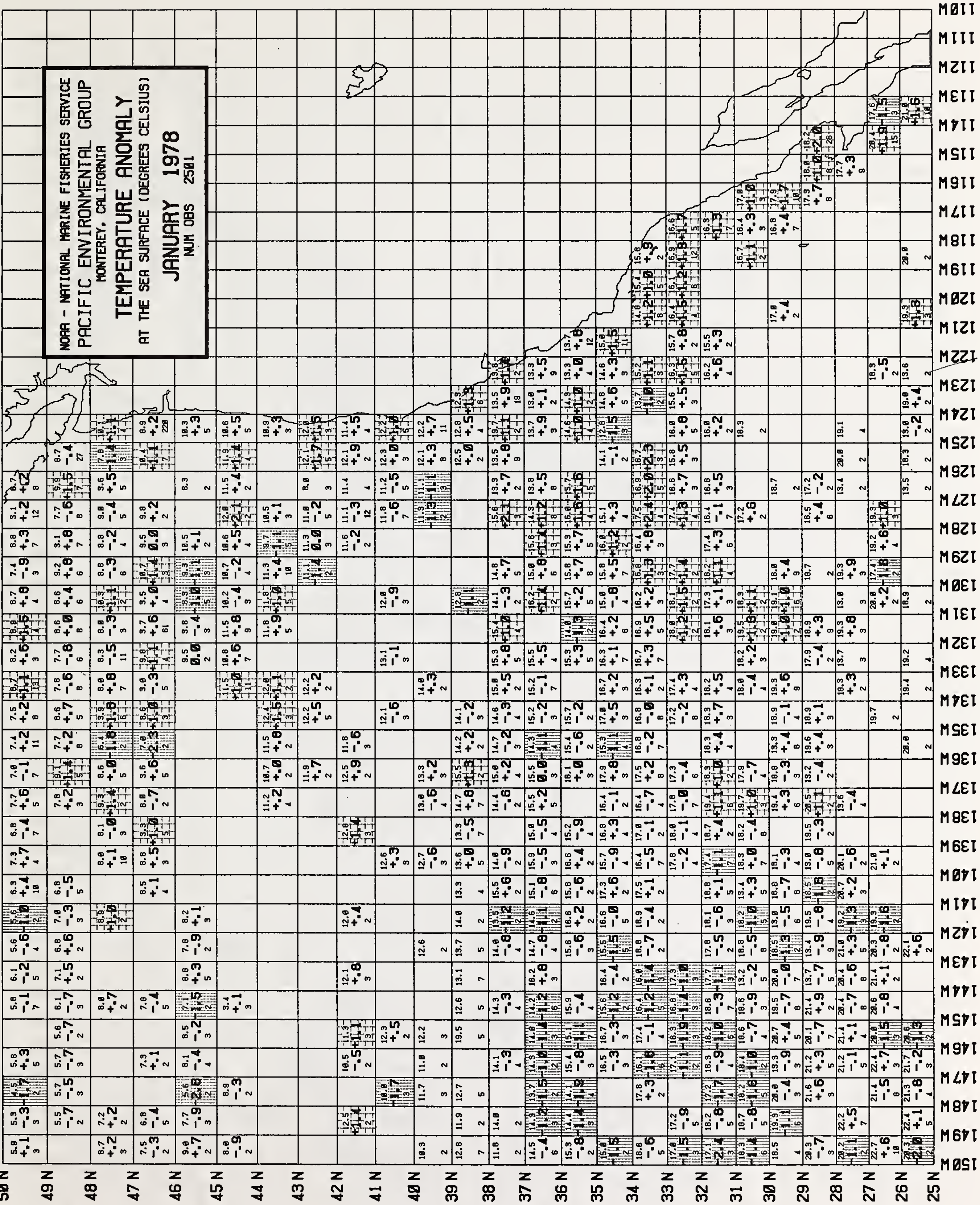
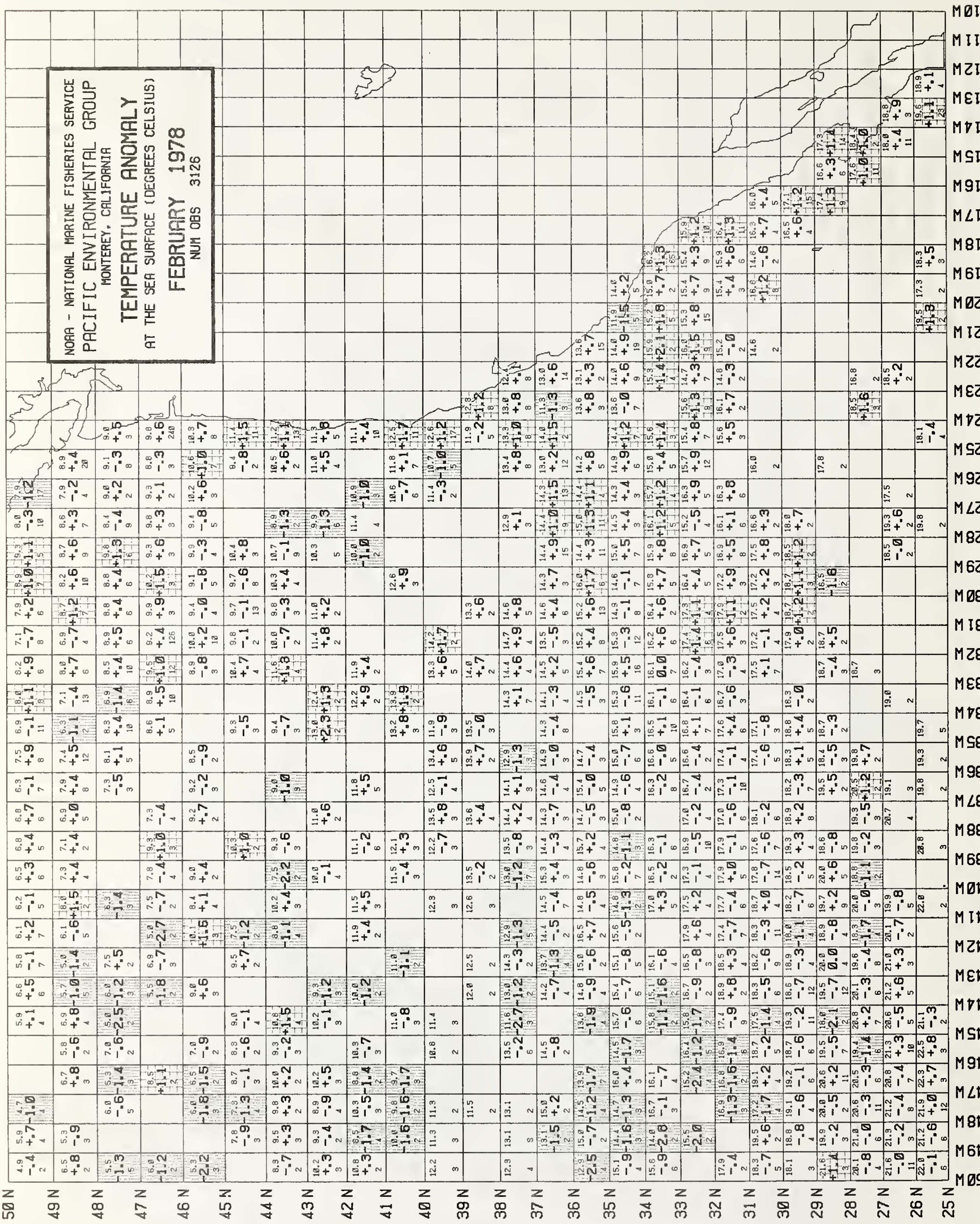
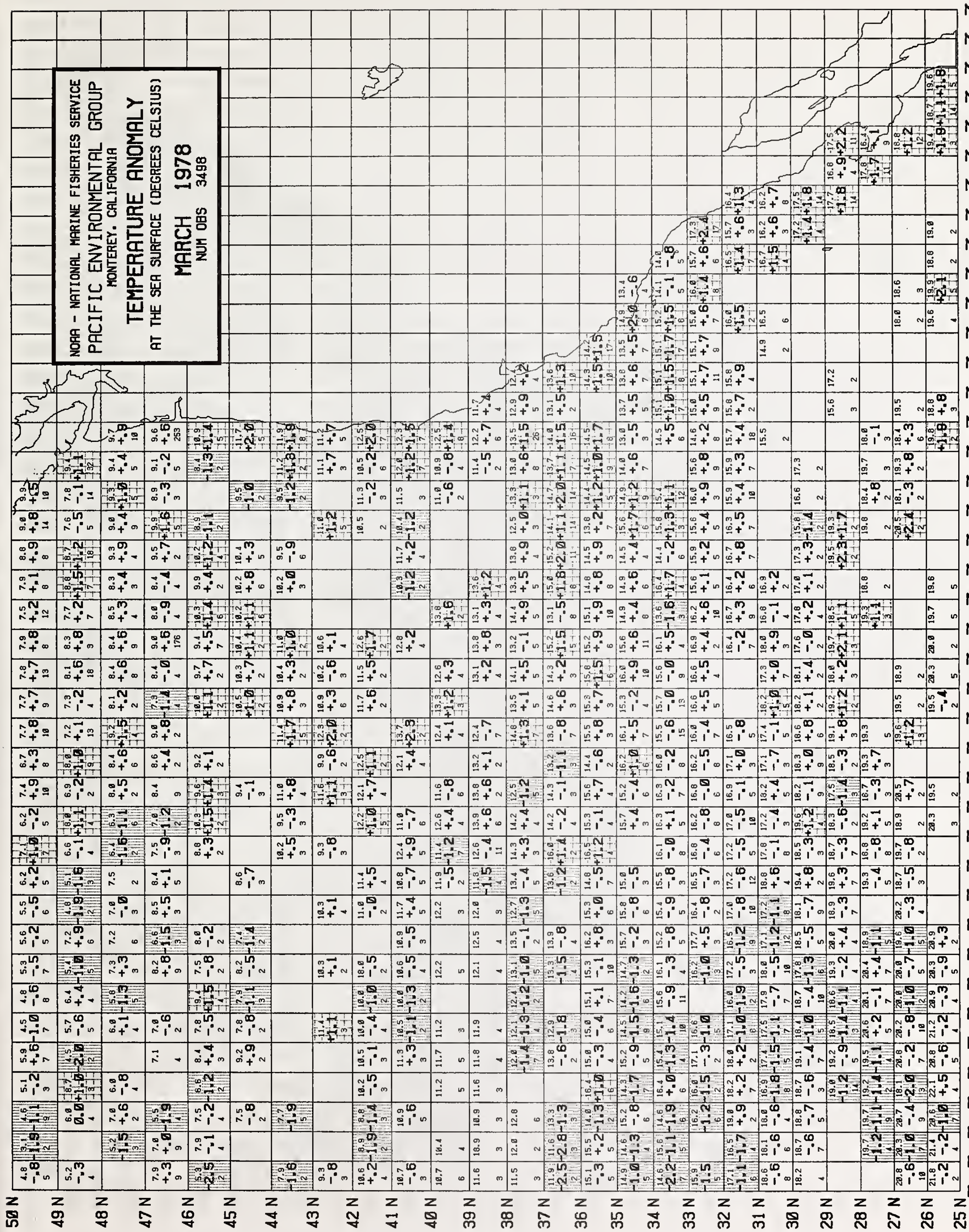
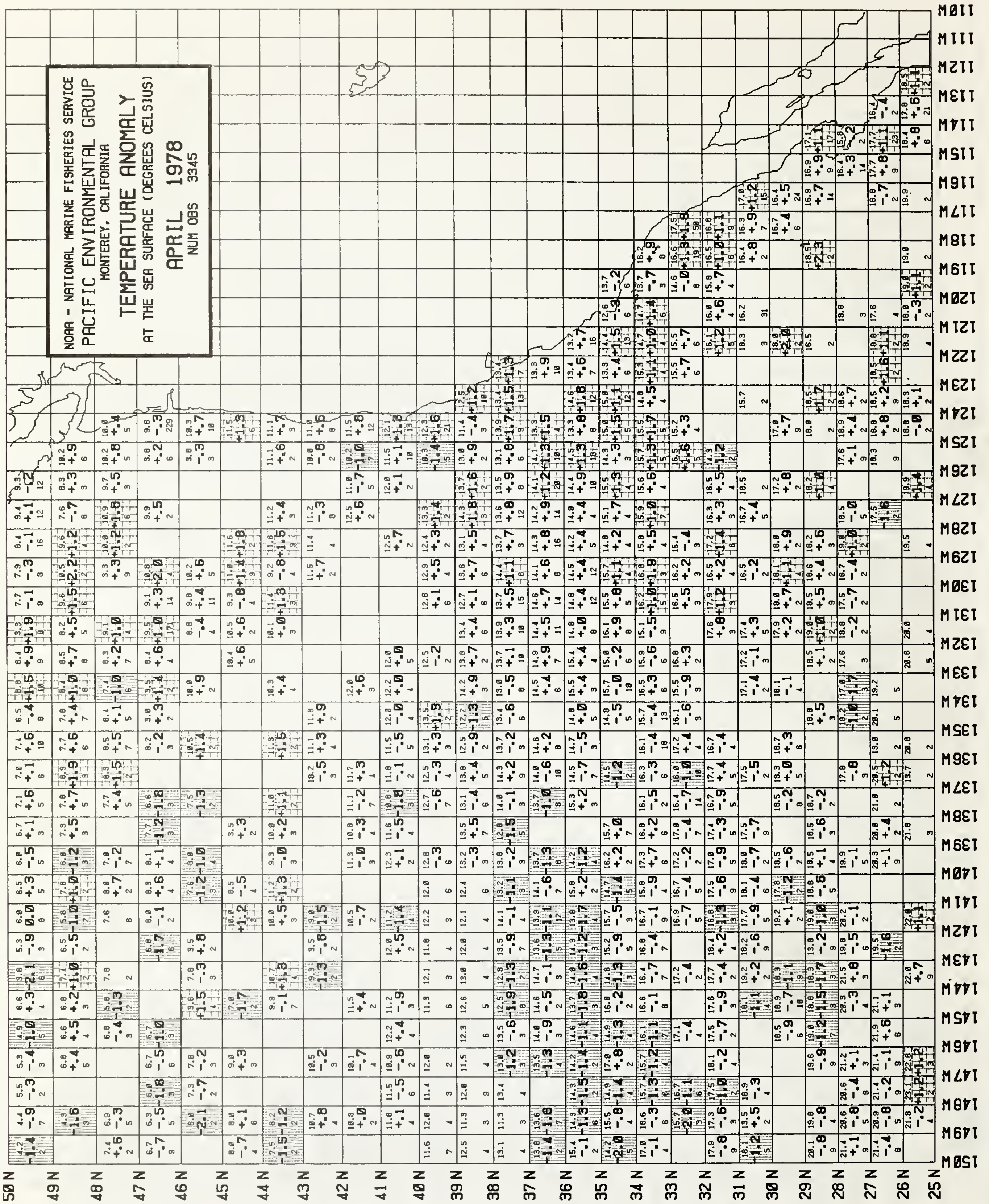

NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JANUARY 1978
NUM OBS 25Ø1
110W 111W 112W 113W 114W 115W 116W 117W 118W 119W 120W 121W 122W 123W 124W 125W 126W 127W 128W 129W 130W 131W 132W 133W 134W 135W 136W 137W 138W 139W 140W 141W 142W 143W 144W 145W 146W 147W 148W 149W 150W
50N 49N 48N 47N 46N 45N 44N 43N 42N 41N 40N 39N 38N 37N 36N 35N 34N 33N 32N 31N 30N 29N 28N 27N 26N 25N


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
FEBRUARY 1978
NUM OBS 3126
50N 49N 48N 47N 46N 45N 44N 43N 42N 41N 40N 39N 38N 37N 36N 35N 34N 33N 32N 31N 30N 29N 28N 27N 26N 25N
150W 149W 148W 147W 146W 145W 144W 143W 142W 141W 140W 139W 138W 137W 136W 135W 134W 133W 132W 131W 130W 129W 128W 127W 126W 125W 124W 123W 122W 121W 120W 119W 118W 117W 116W 115W 114W 113W 112W 111W 110W


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MARCH 1978
NUM OBS 3498


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
APRIL 1978
NUM OBS 3345
50N
49N
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47N
46N
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44N
43N
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41N
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33N
32N
31N
30N
29N
28N
27N
26N
25N
150W
149W
148W
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129W
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126W
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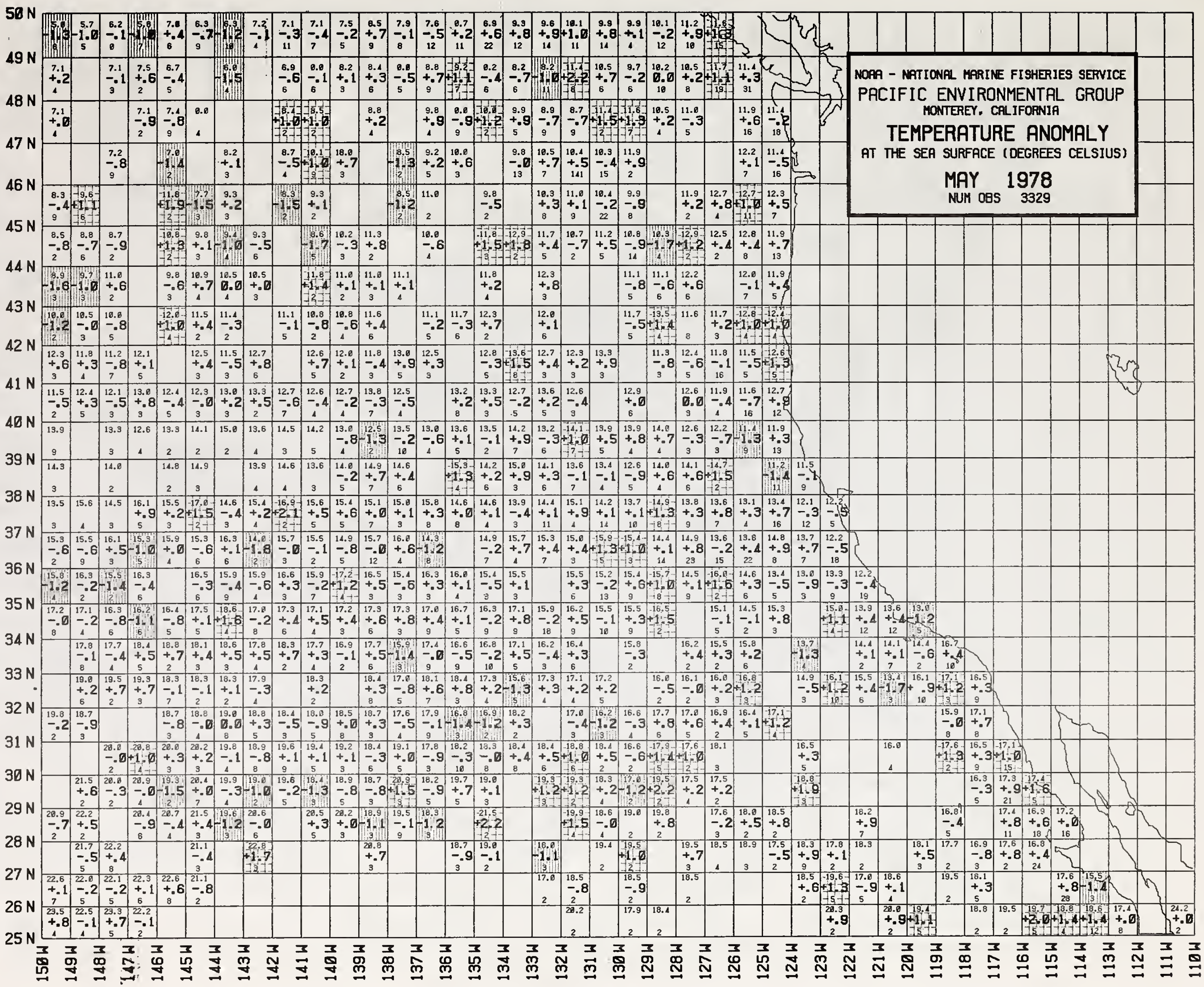
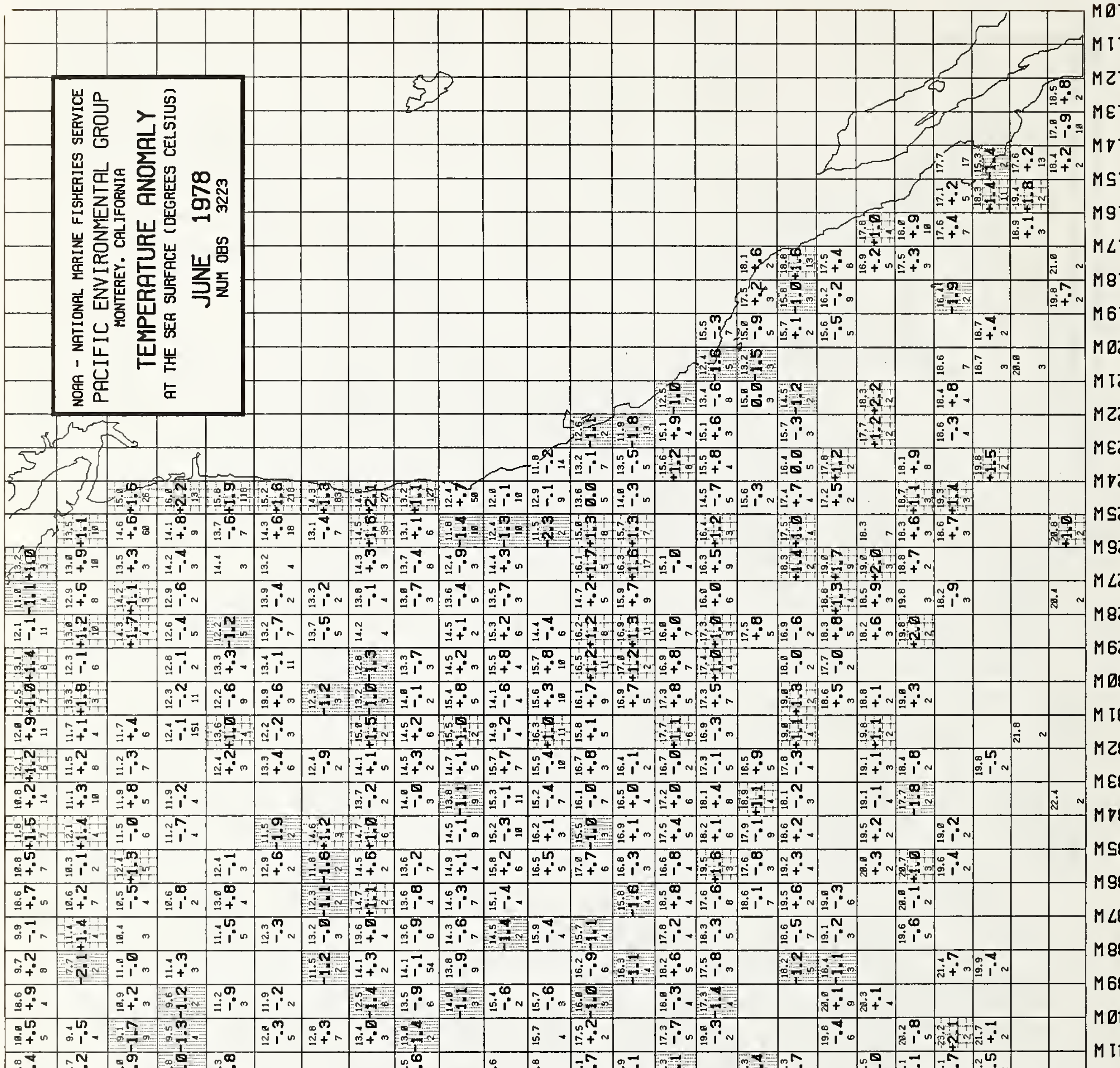
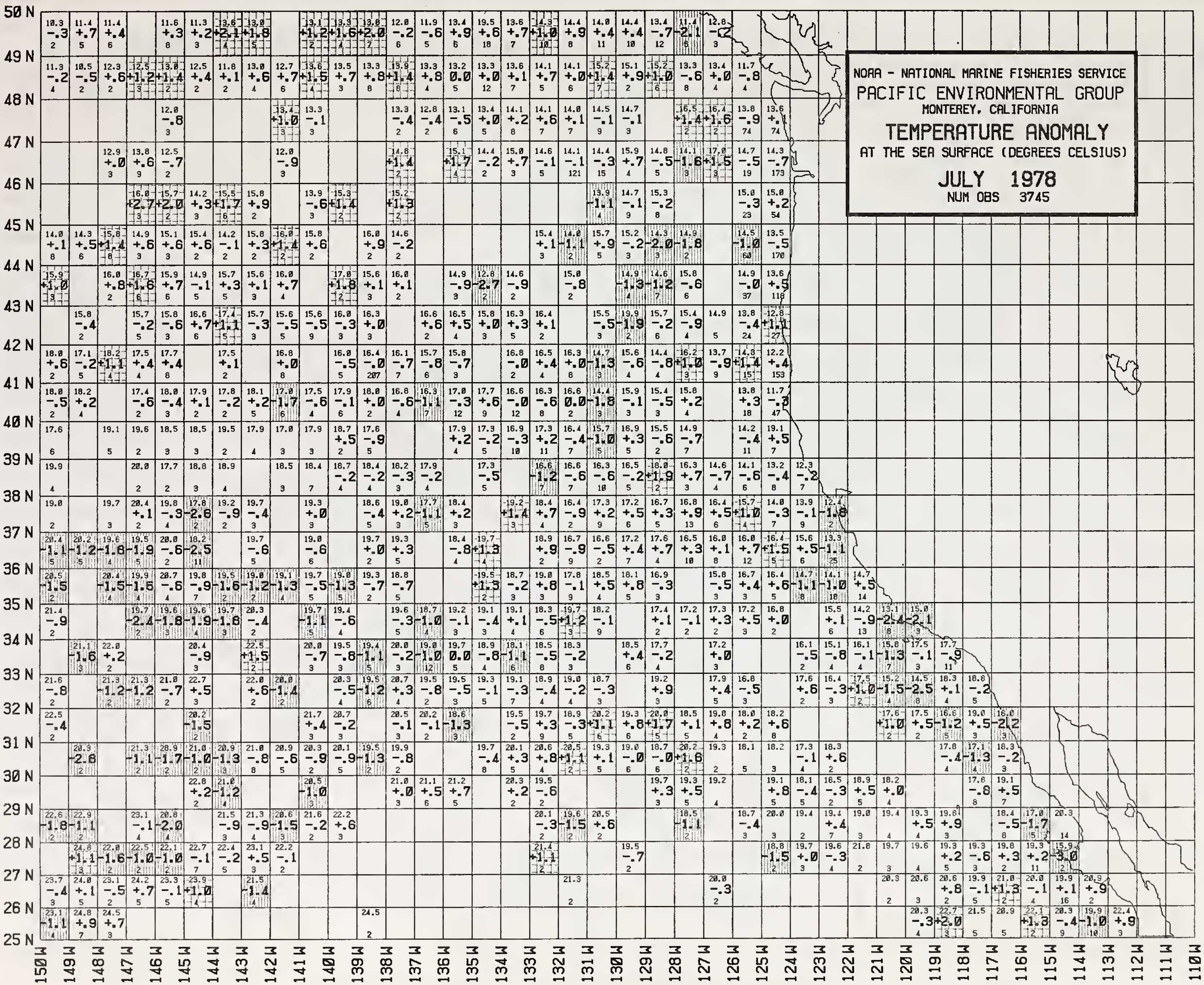
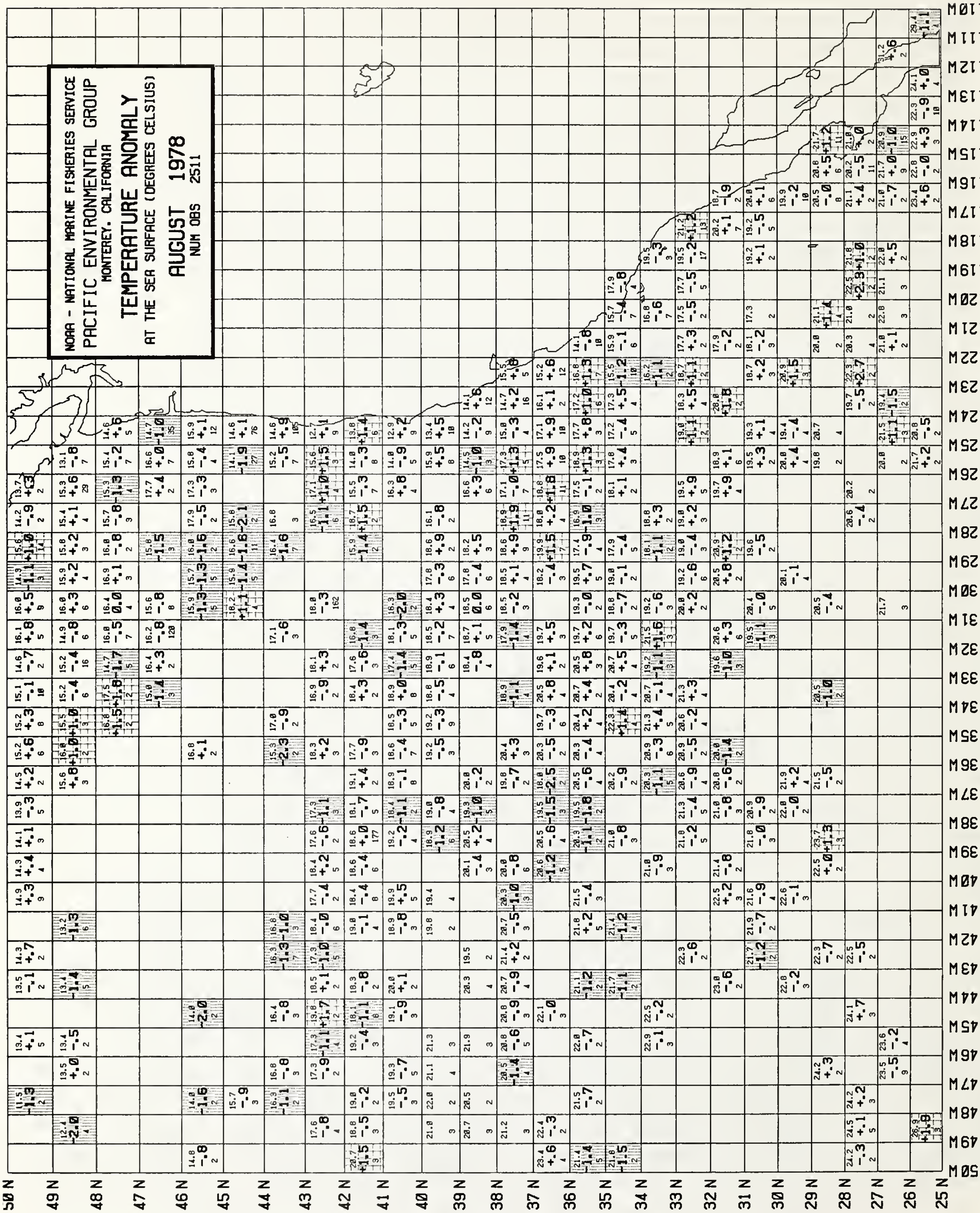
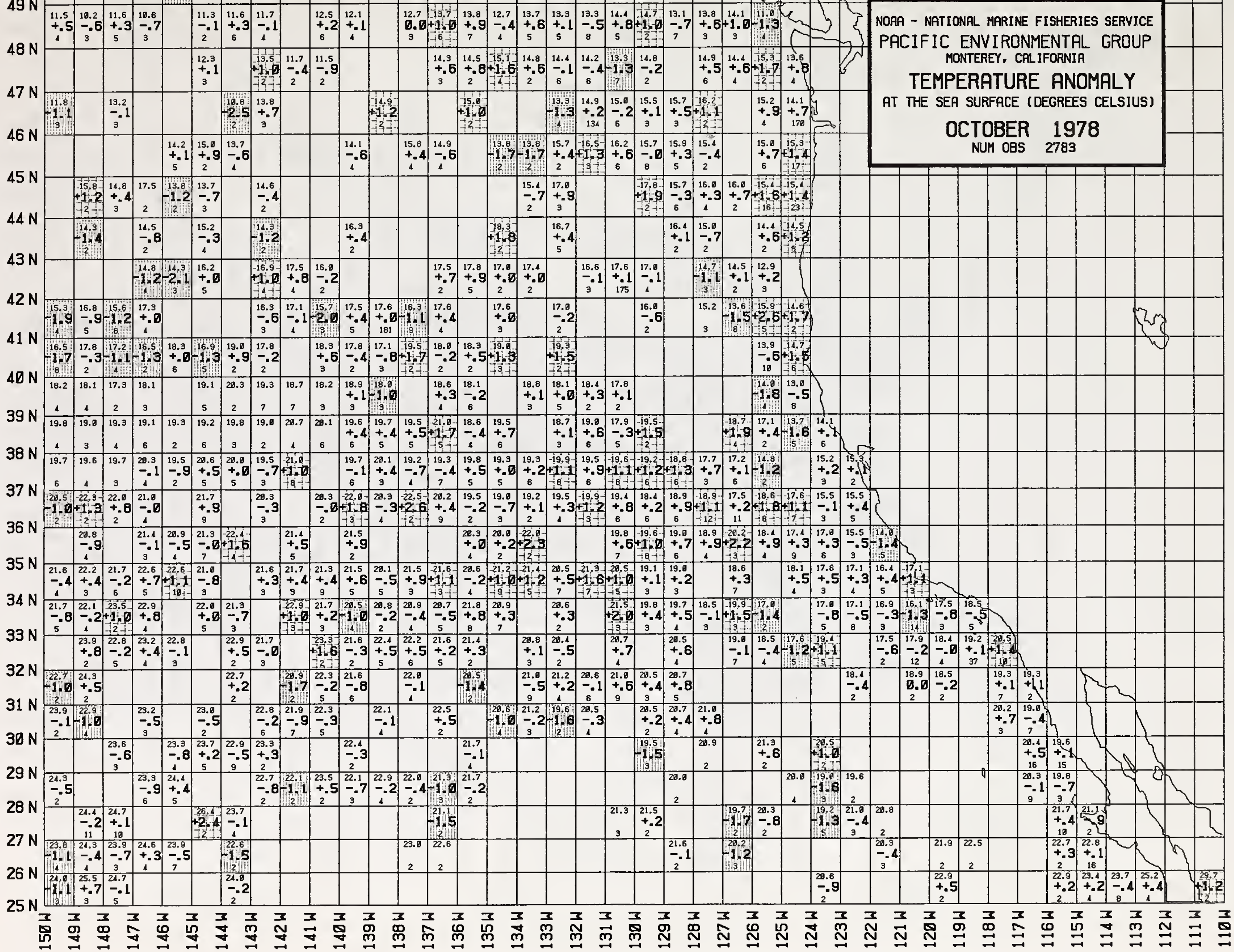
111W
110W

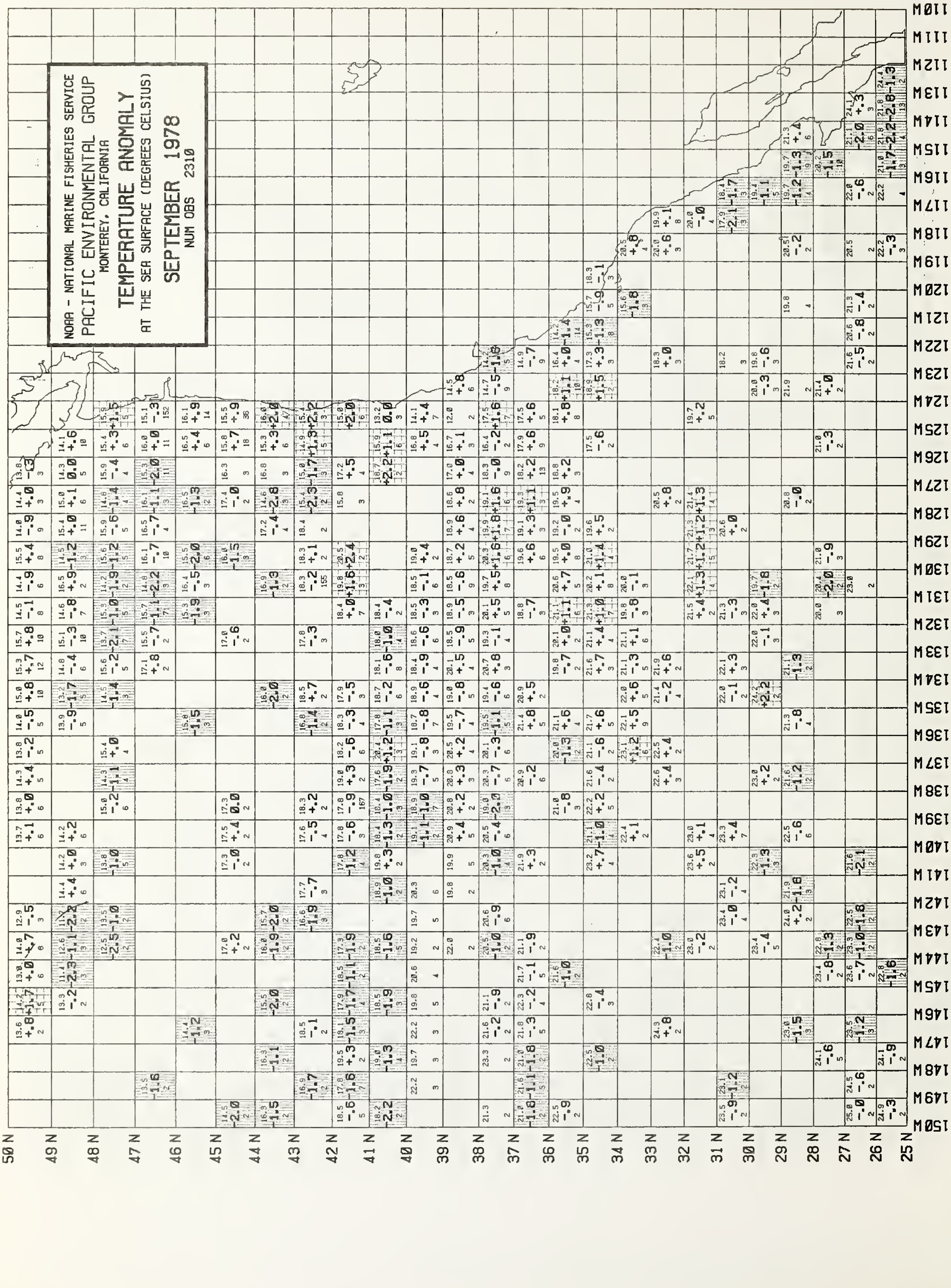

NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MAY 1978
NUM OBS 3329
50N 49N 48N 47N 46N 45N 44N 43N 42N 41N 40N 39N 38N 37N 36N 35N 34N 33N 32N 31N 30N 29N 28N 27N 26N 25N
150W 149W 148W 147W 146W 145W 144W 143W 142W 141W 140W 139W 138W 137W 136W 135W 134W 133W 132W 131W 130W 129W 128W 127W 126W 125W 124W 123W 122W 121W 120W 119W 118W 117W 116W 115W 114W 113W 112W 111W 110W

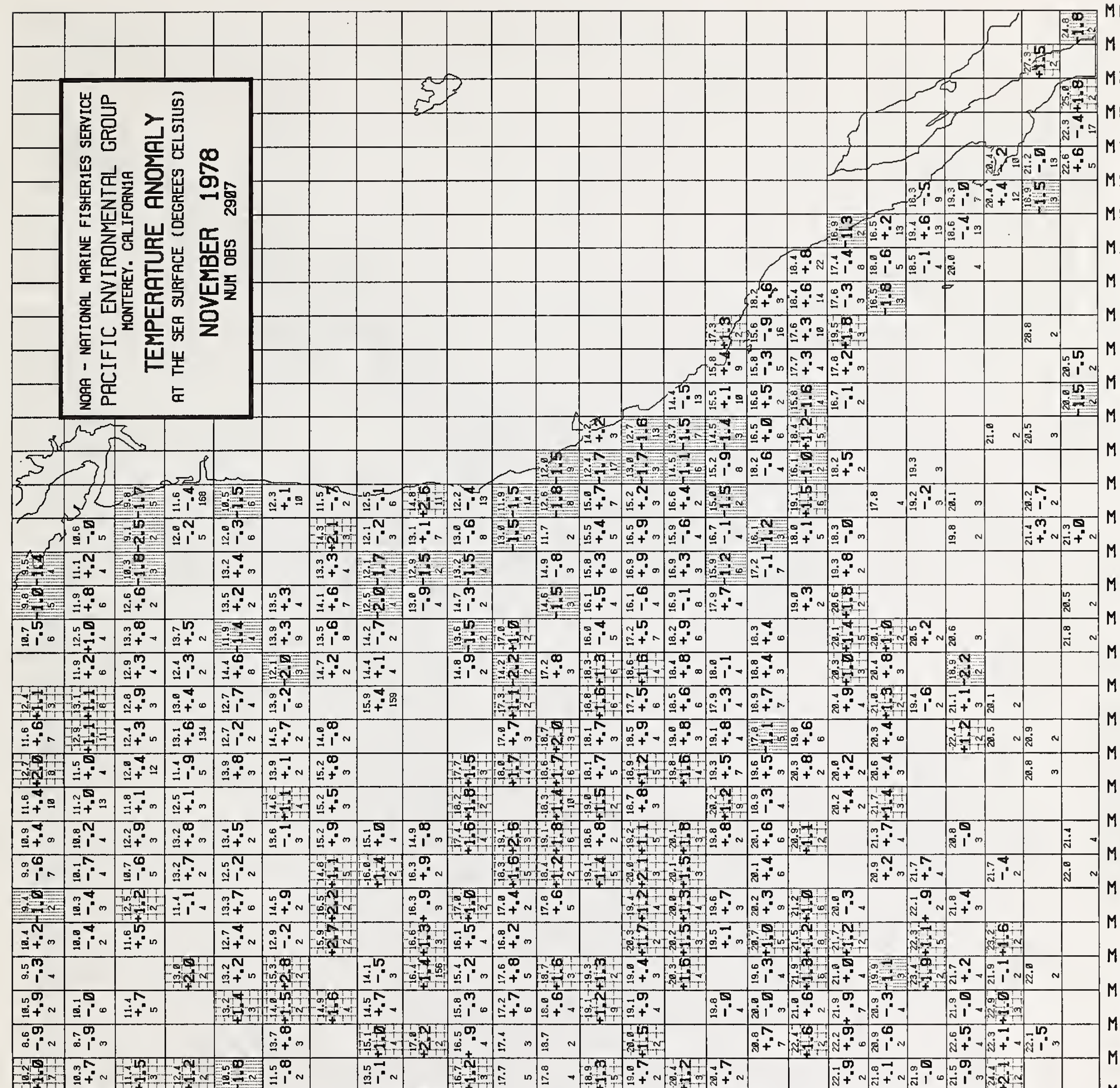

NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JUNE 1978
NUM OBS 3223

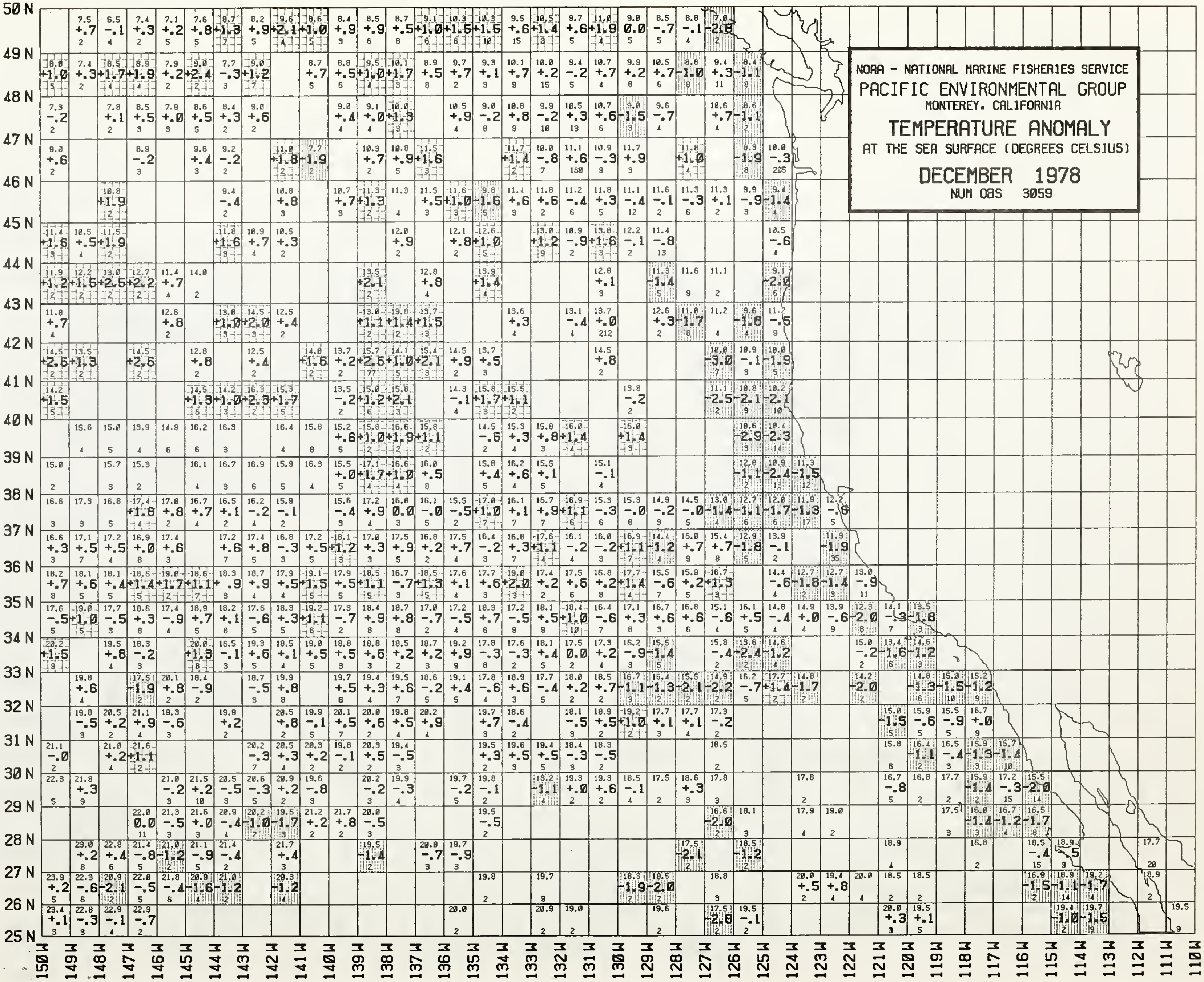

NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JULY 1978
NUM OBS 3745


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
AUGUST 1978
NUM OBS 2511
50N 49N 48N 47N 46N 45N 44N 43N 42N 41N 40N 39N 38N 37N 36N 35N 34N 33N 32N 31N 30N 29N 28N 27N 26N 25N
110W 111W 112W 113W 114W 115W 116W 117W 118W 119W 120W 121W 122W 123W 124W 125W 126W 127W 128W 129W 130W 131W 132W 133W 134W 135W 136W 137W 138W 139W 140W 141W 142W 143W 144W 145W 146W 147W 148W 149W 150W


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
OCTOBER 1978
NUM OBS 2783


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
SEPTEMBER 1978
NUM OBS 2310


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
NOVEMBER 1978
NUM OBS 2907


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
DECEMBER 1978
NUM OBS 3059
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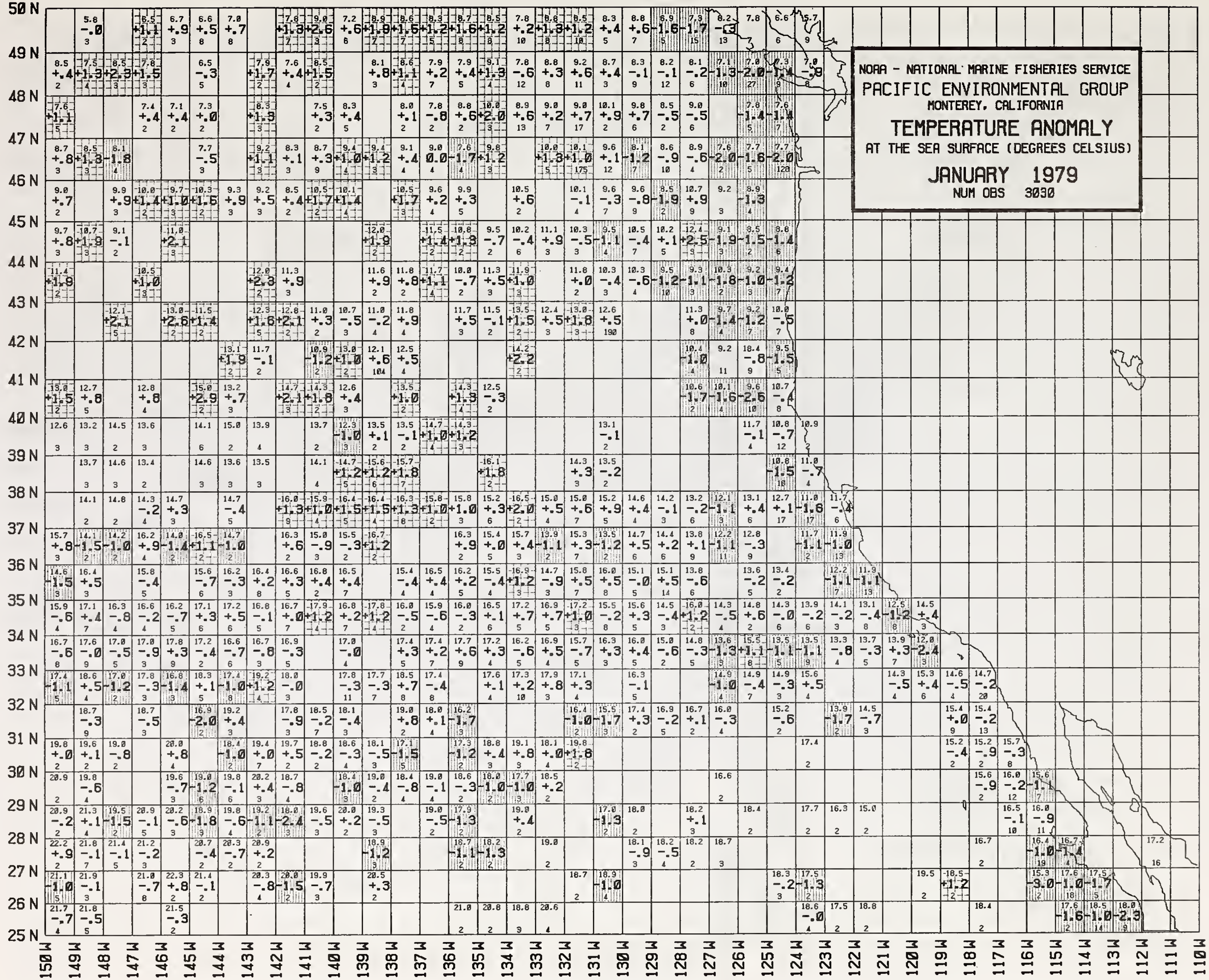
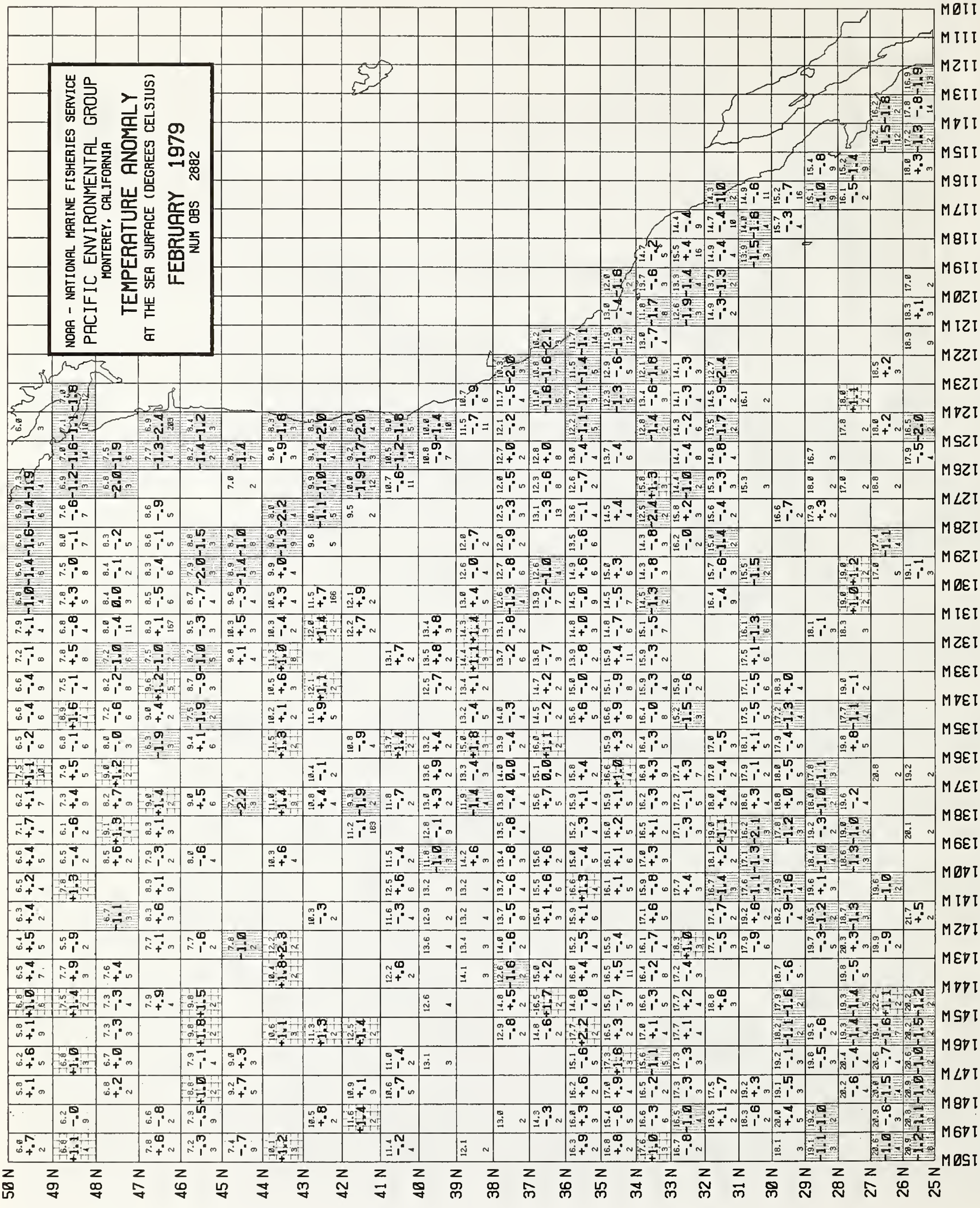
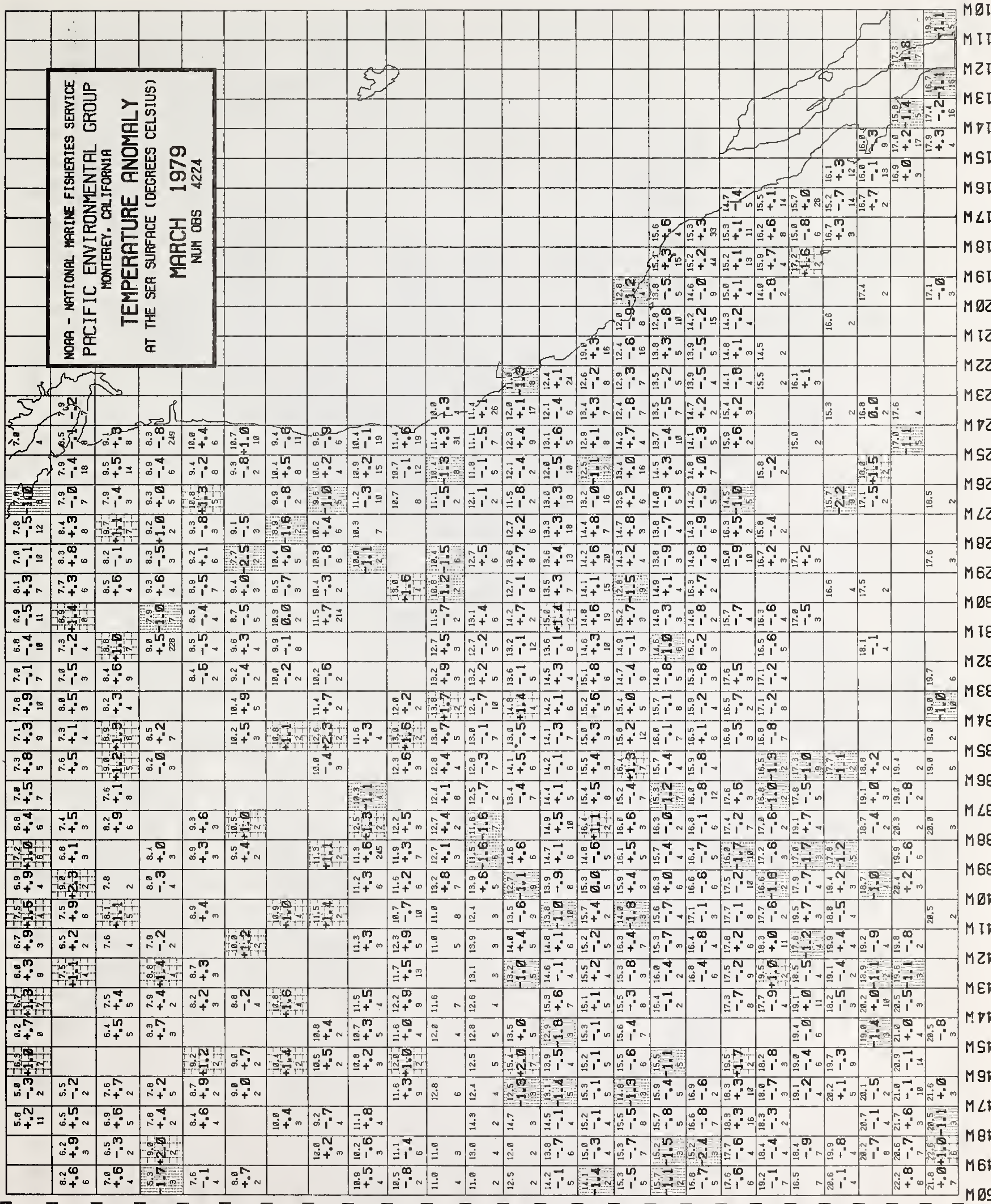
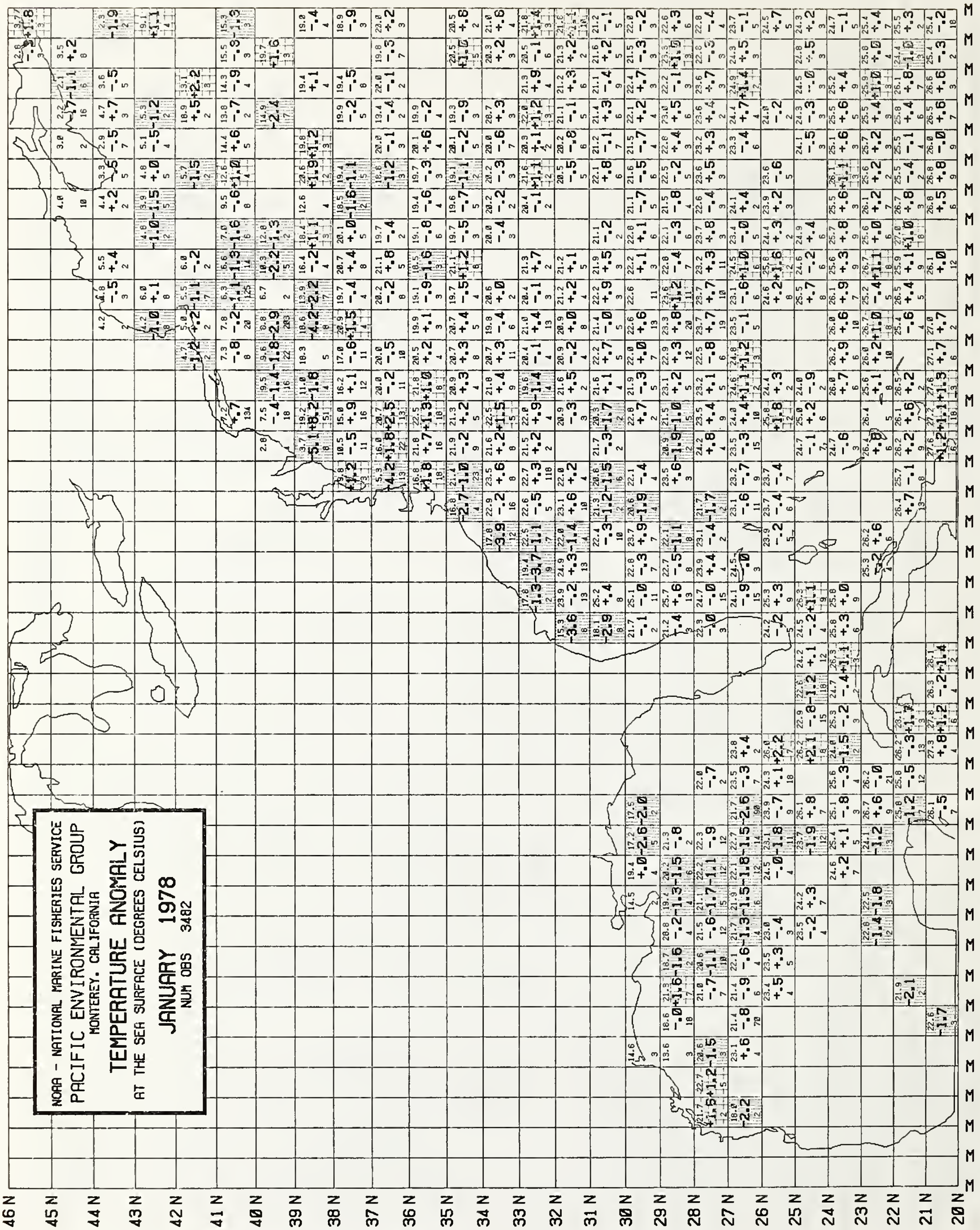

NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JANUARY 1979
NUM OBS 3030
50N 49N 48N 47N 46N 45N 44N 43N 42N 41N 40N 39N 38N 37N 36N 35N 34N 33N 32N 31N 30N 29N 28N 27N 26N 25N
150W 149W 148W 147W 146W 145W 144W 143W 142W 141W 140W 139W 138W 137W 136W 135W 134W 133W 132W 131W 130W 129W 128W 127W 126W 125W 124W 123W 122W 121W 120W 119W 118W 117W 116W 115W 114W 113W 112W 111W 110W


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
FEBRUARY 1979
NUM OBS 2882


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MARCH 1979
NUM OBS 4224


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JANUARY 1978
NUM OBS 3482
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43 N
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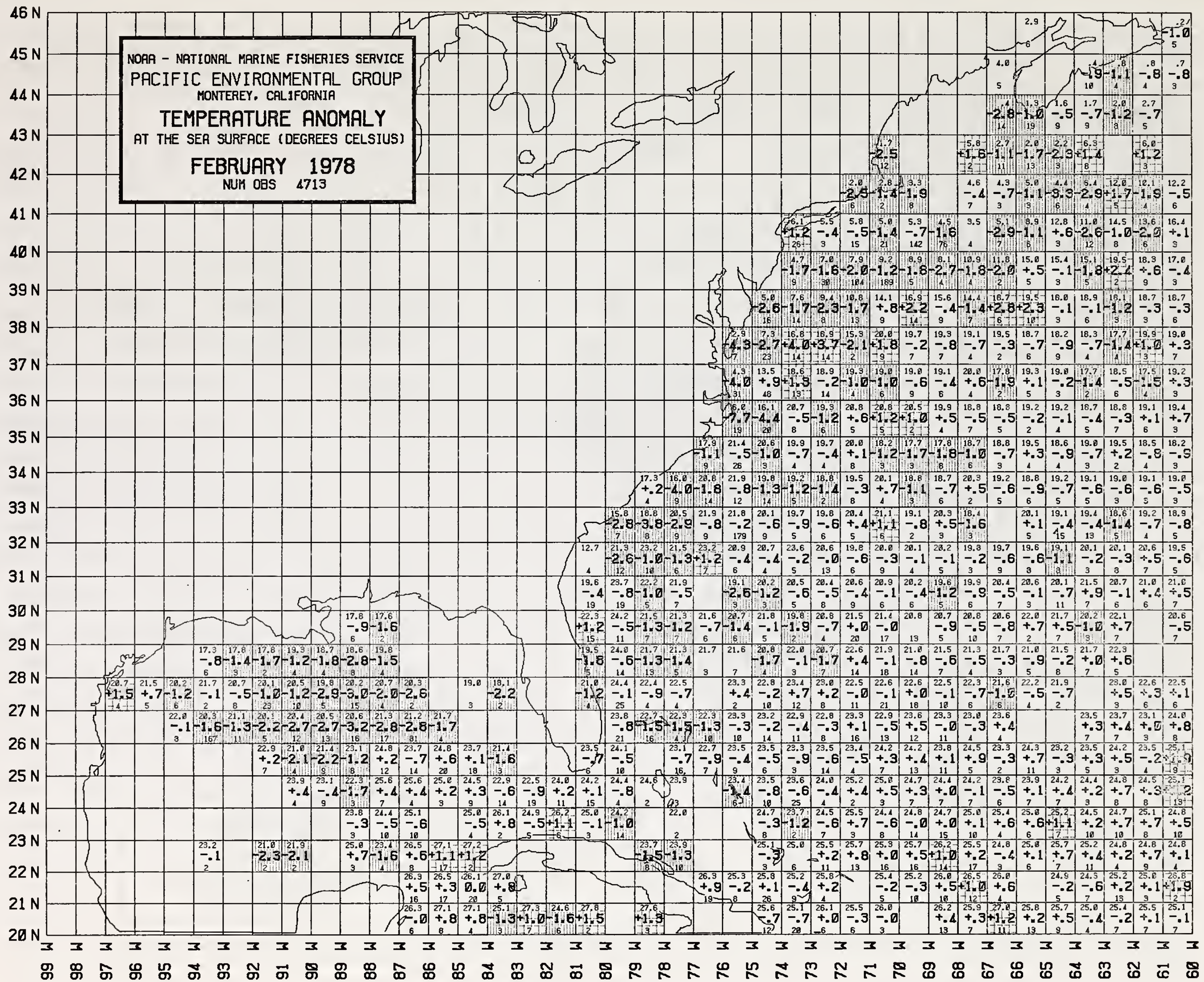
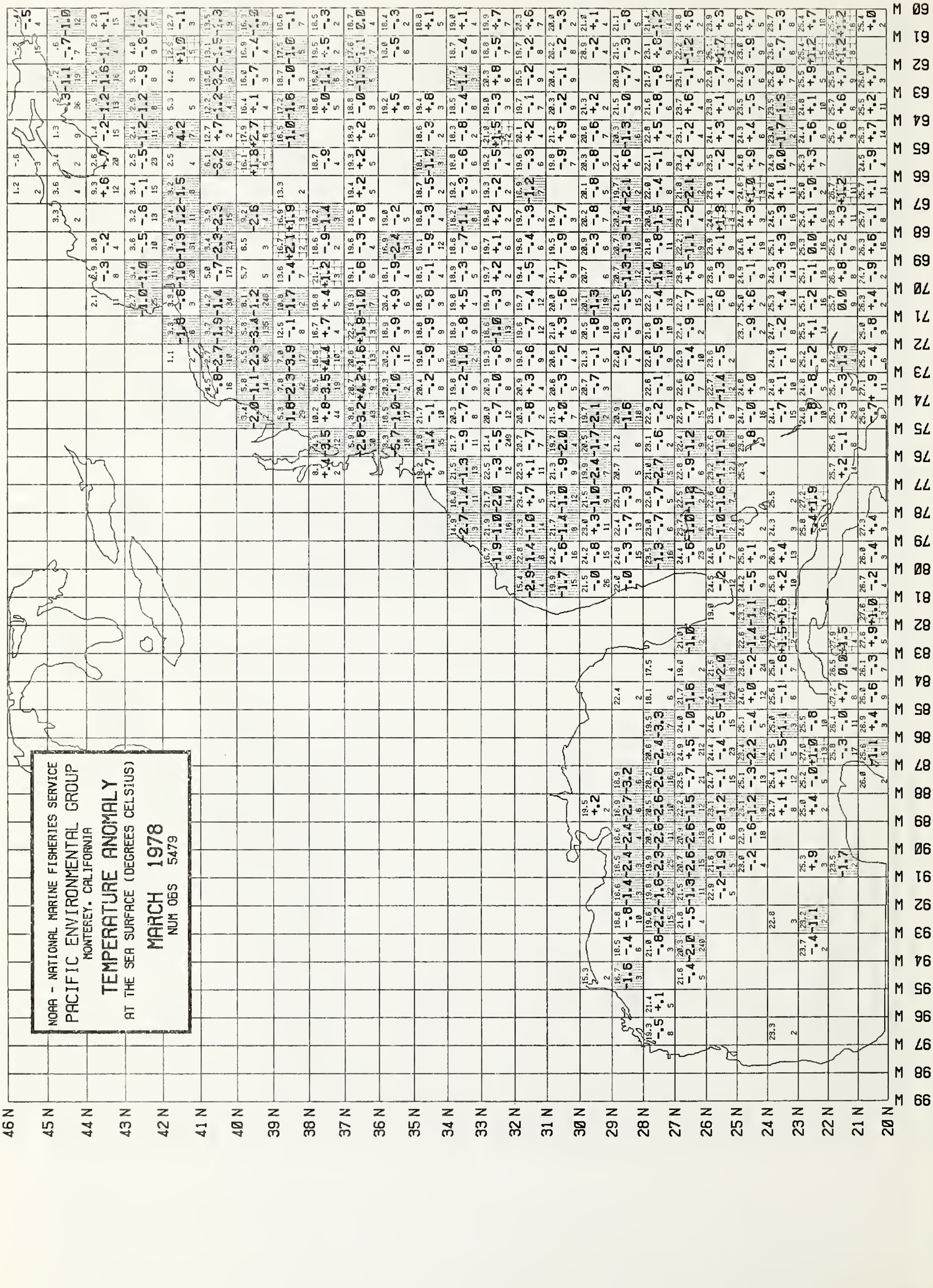
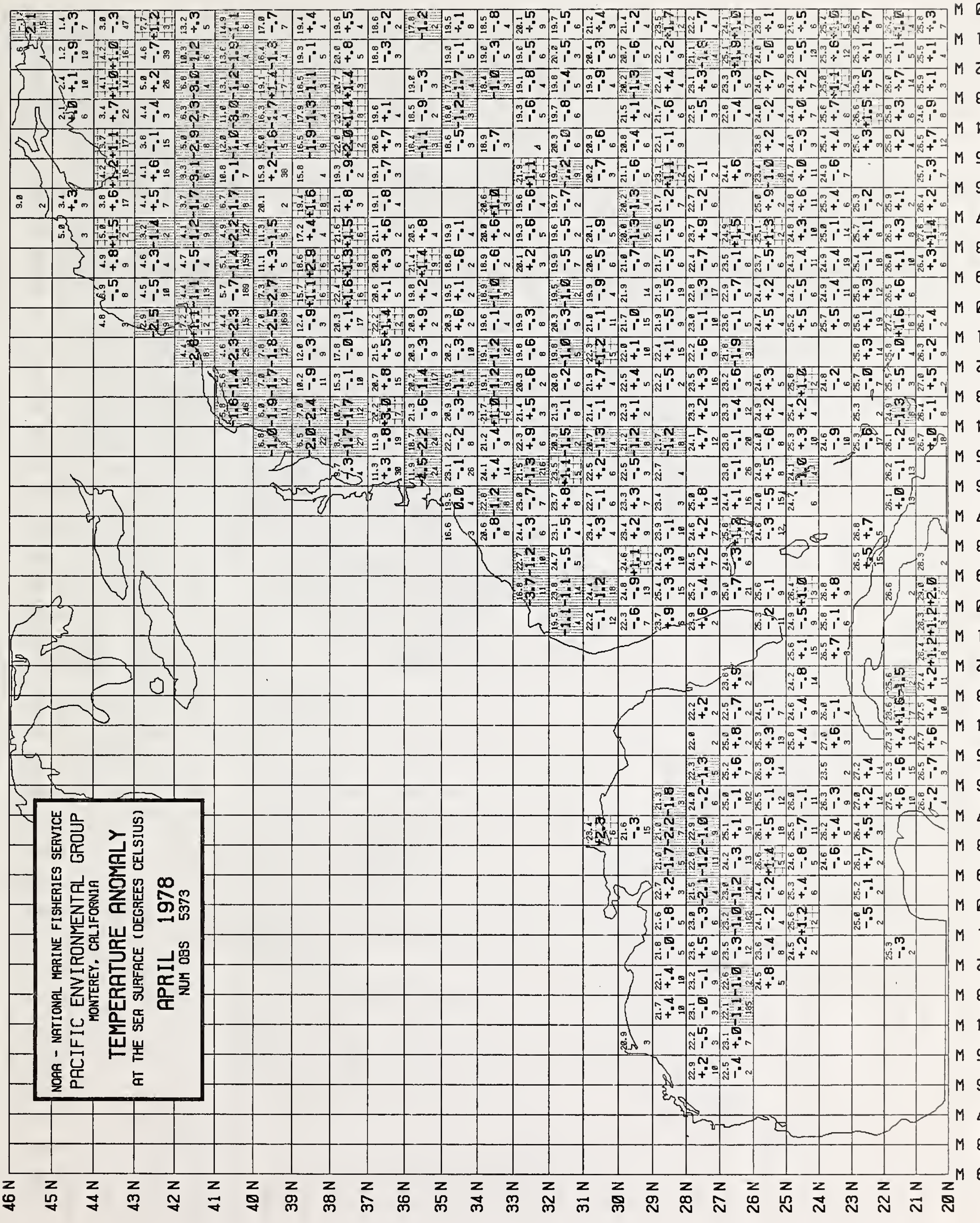
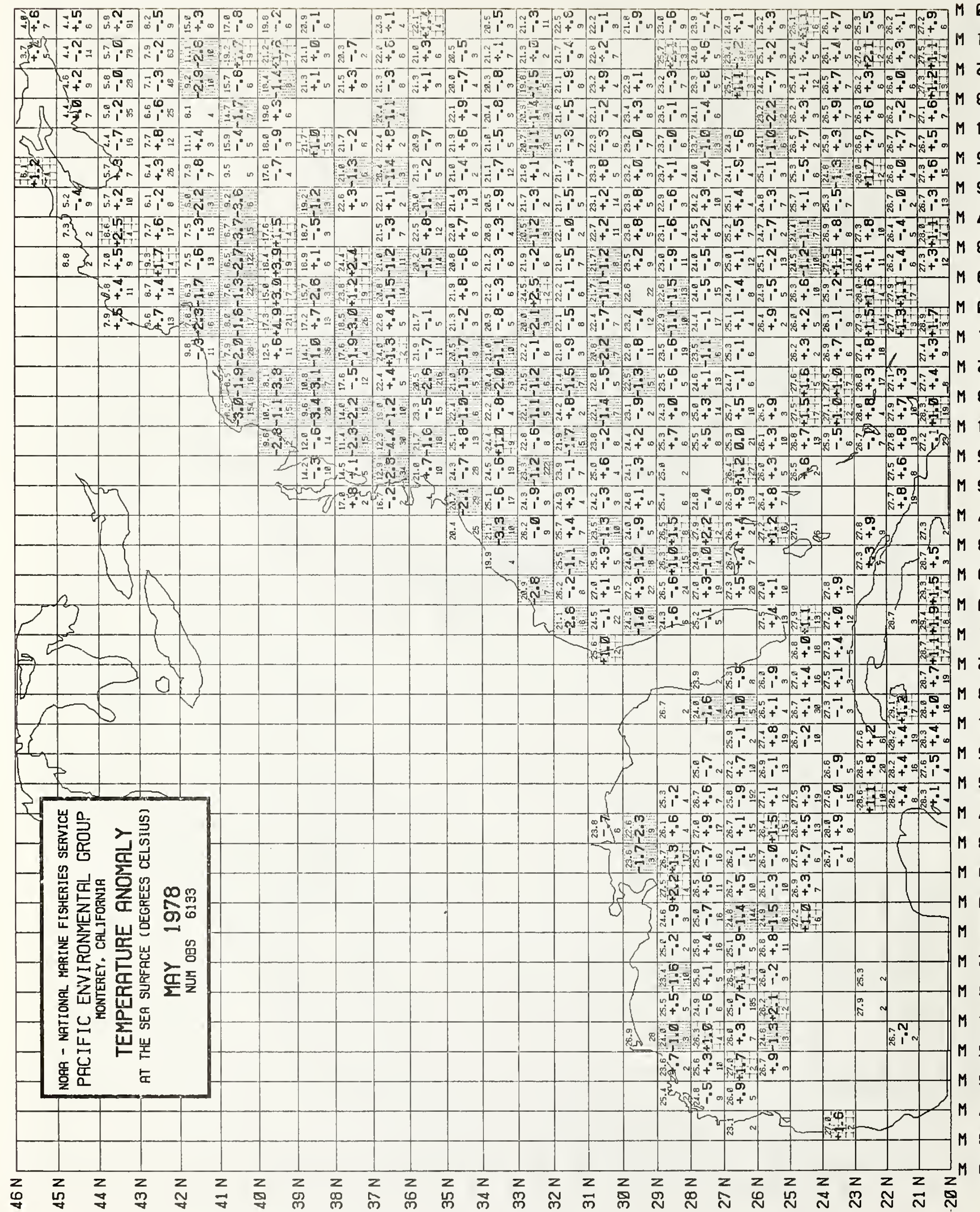
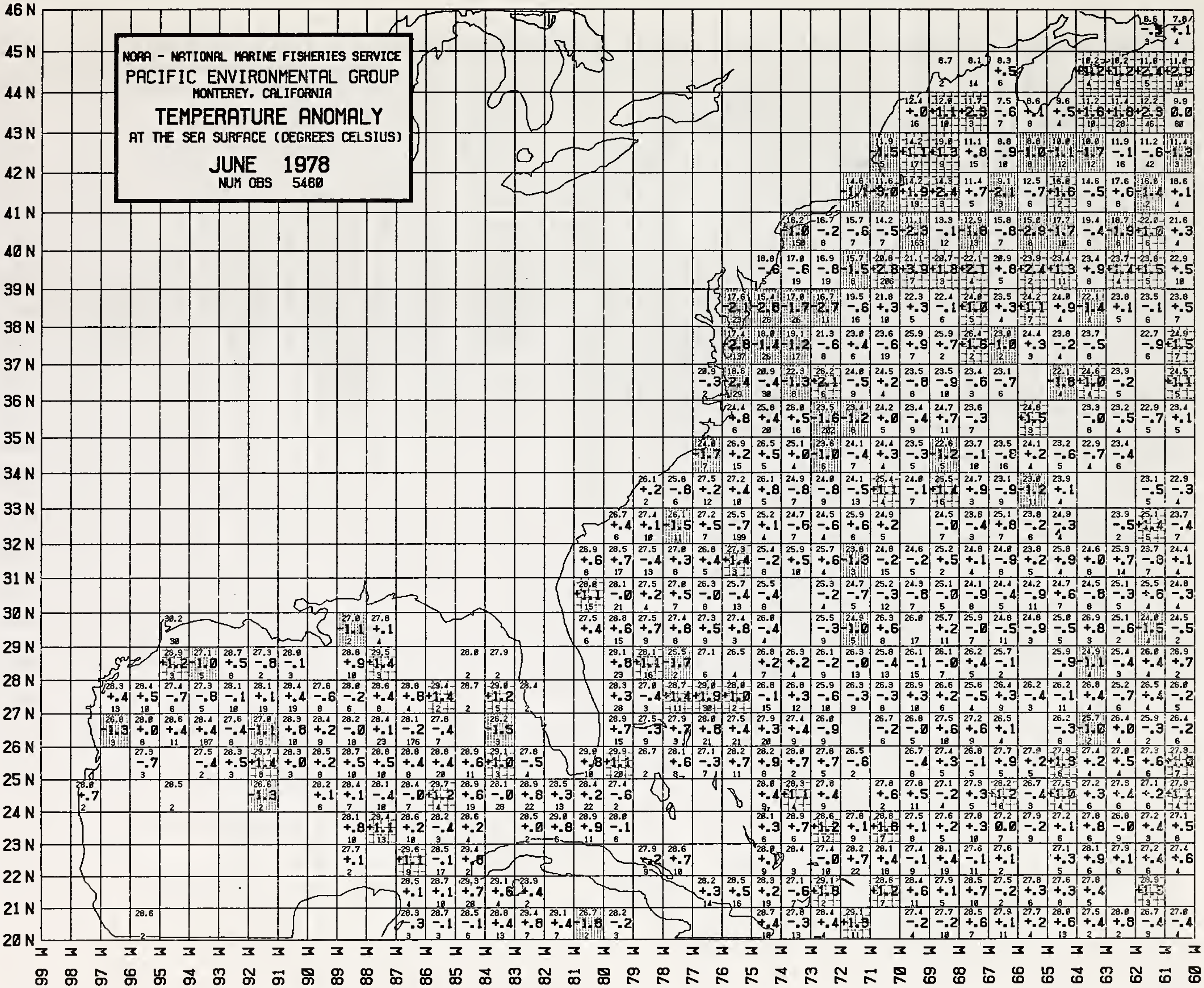

NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
FEBRUARY 1978
NUM OBS 4713


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MARCH 1978
NUM OBS 5479


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
APRIL 1978
NUM OBS 5373


NOAA - NATIONAL MARINE FISHERIES SERVICE
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
MAY 1978
NUM OBS 6133
46 N 45 N 44 N 43 N 42 N 41 N 40 N 39 N 38 N 37 N 36 N 35 N 34 N 33 N 32 N 31 N 30 N 29 N 28 N 27 N 26 N 25 N 24 N 23 N 22 N 21 N 20 N
60 W 61 W 62 W 63 W 64 W 65 W 66 W 67 W 68 W 69 W 70 W 71 W 72 W 73 W 74 W 75 W 76 W 77 W 78 W 79 W 80 W 81 W 82 W 83 W 84 W 85 W 86 W 87 W 88 W 89 W 90 W 91 W 92 W 93 W 94 W 95 W 96 W 97 W 98 W 99 W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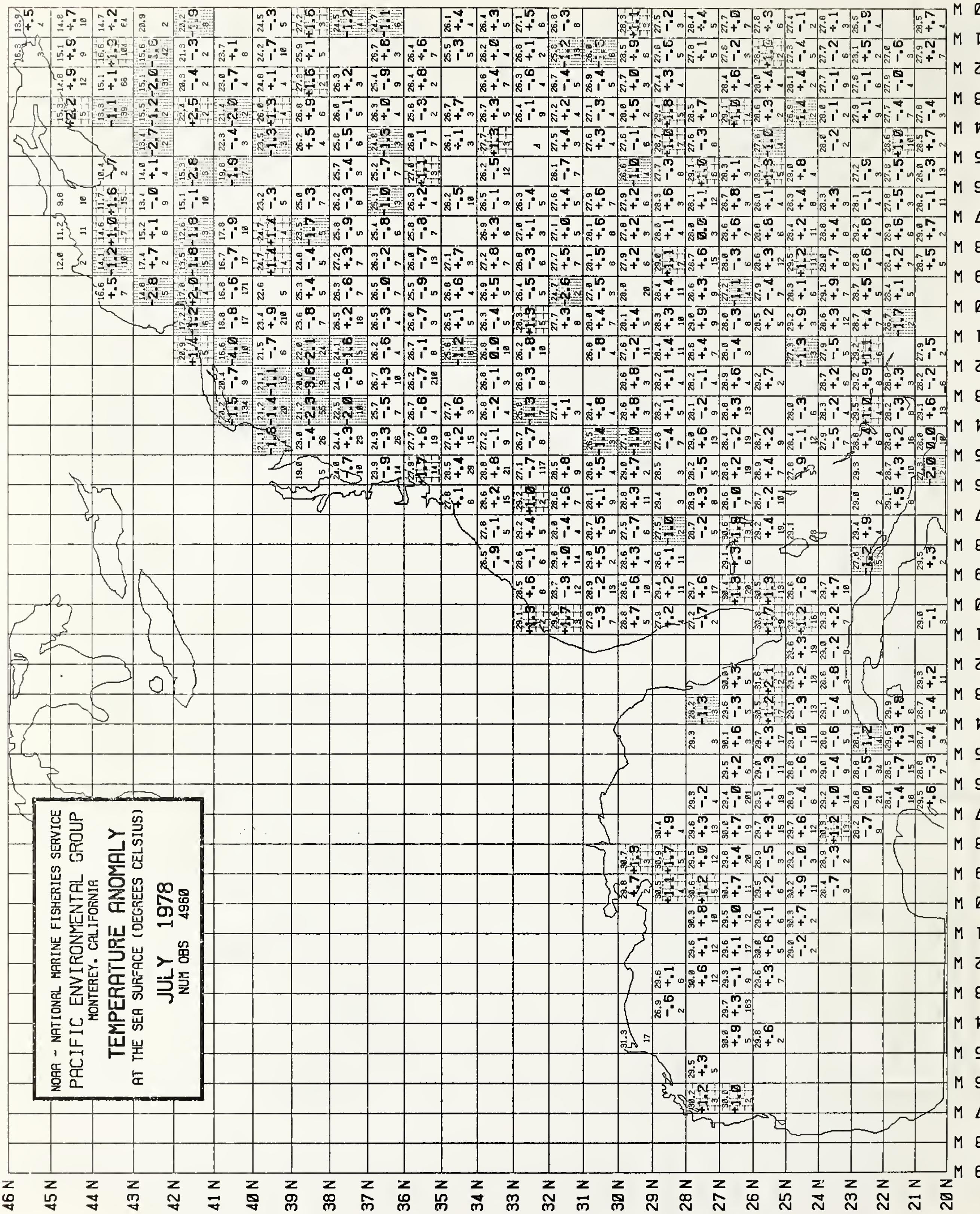
PACIFIC ENVIRONMENTAL GROUP
MONTEREY, CALIFORNIA
TEMPERATURE ANOMALY
AT THE SEA SURFACE (DEGREES CELSIUS)
JUNE 1978
NUM OBS 5460



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JULY 1978
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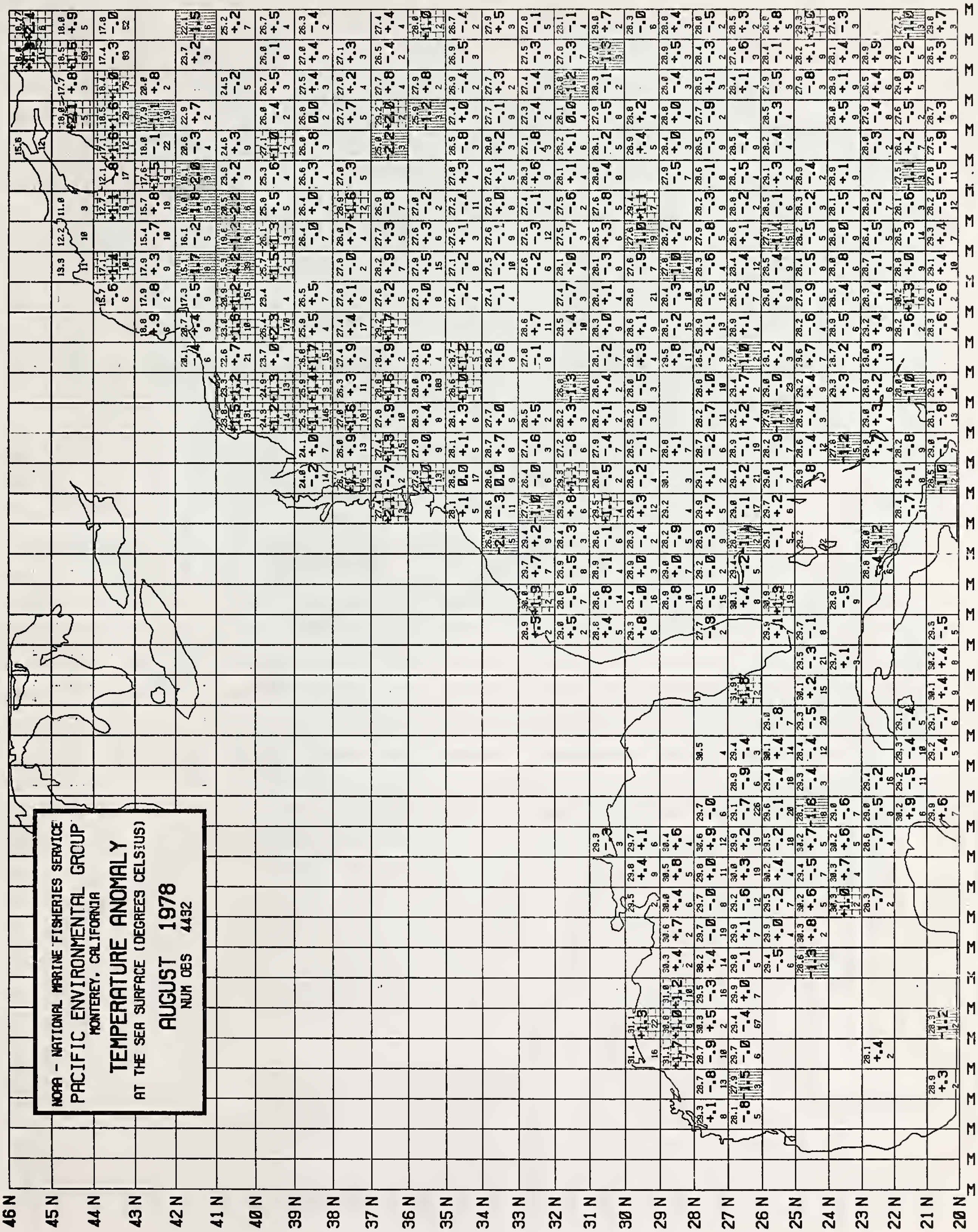
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AUGUST 1978
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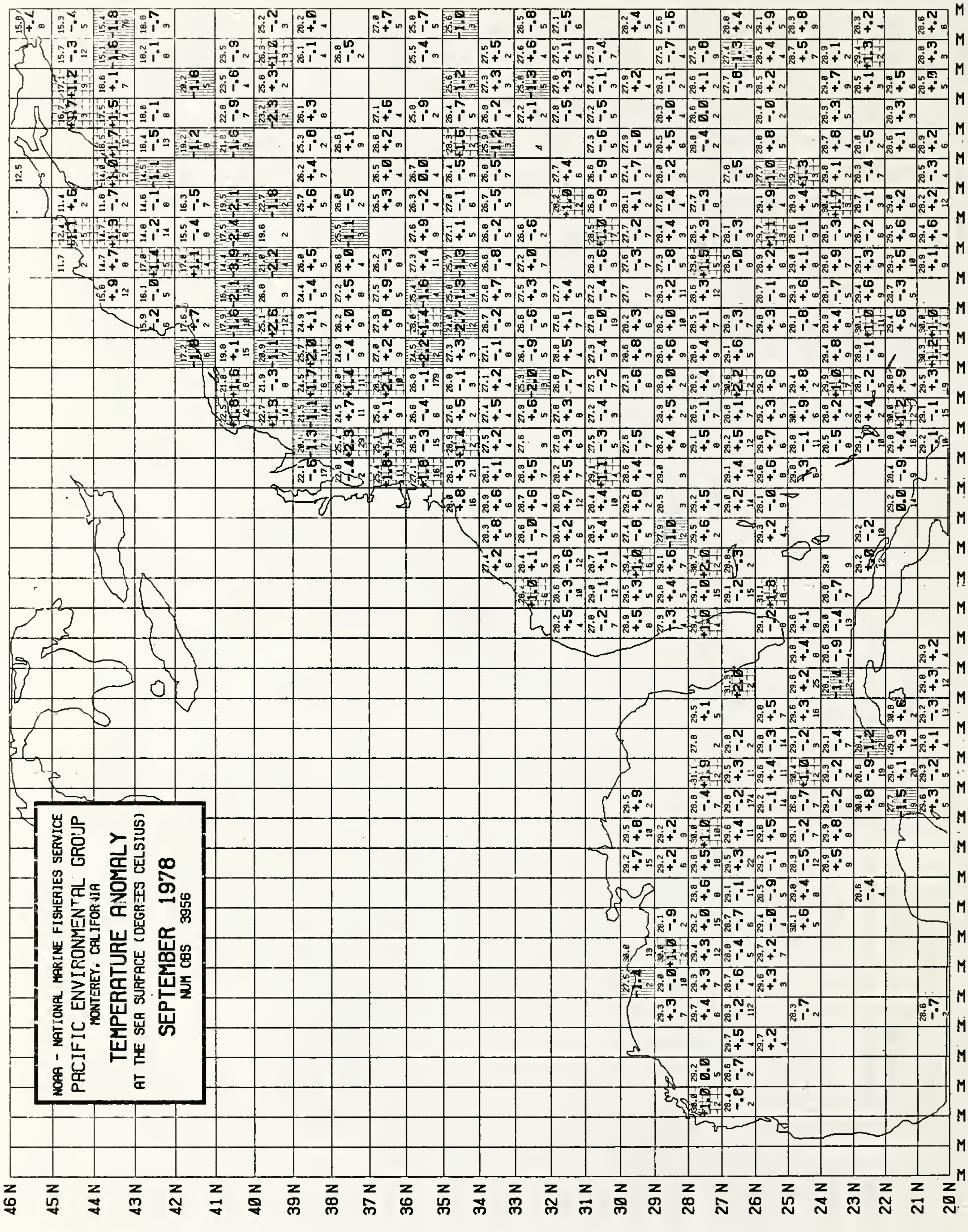
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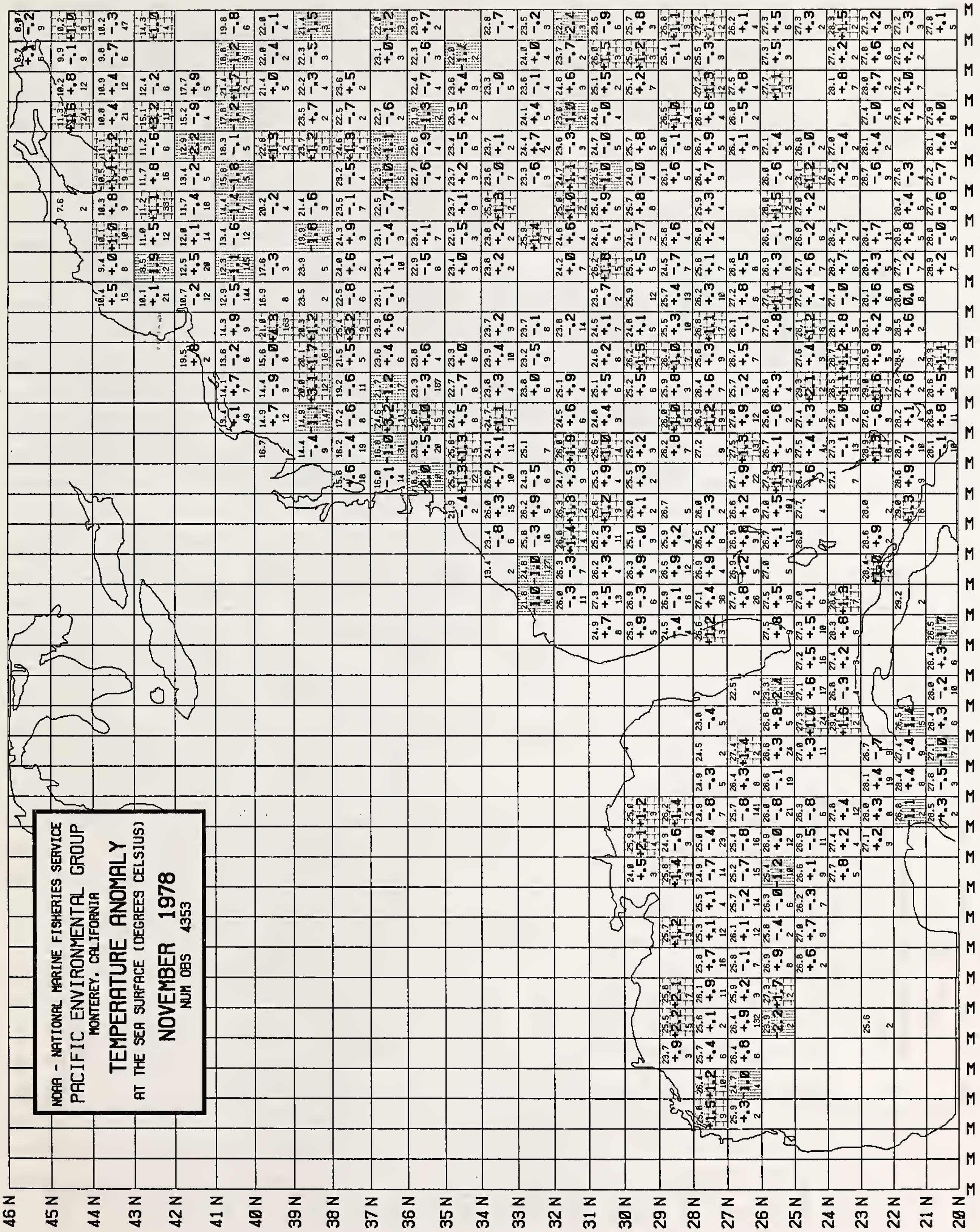
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TEMPERATURE ANOMALY
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NOVEMBER 1978
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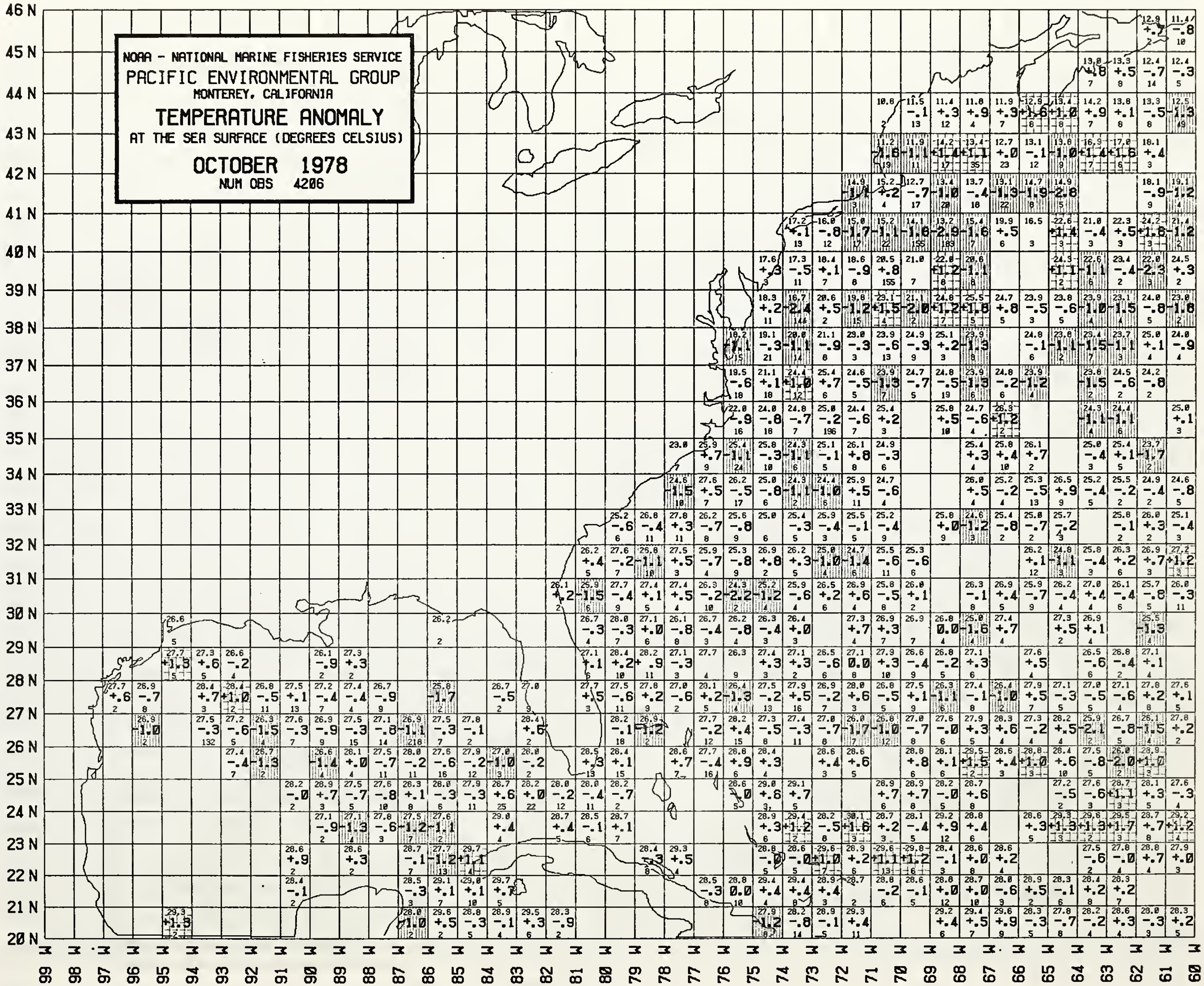
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TEMPERATURE ANOMALY
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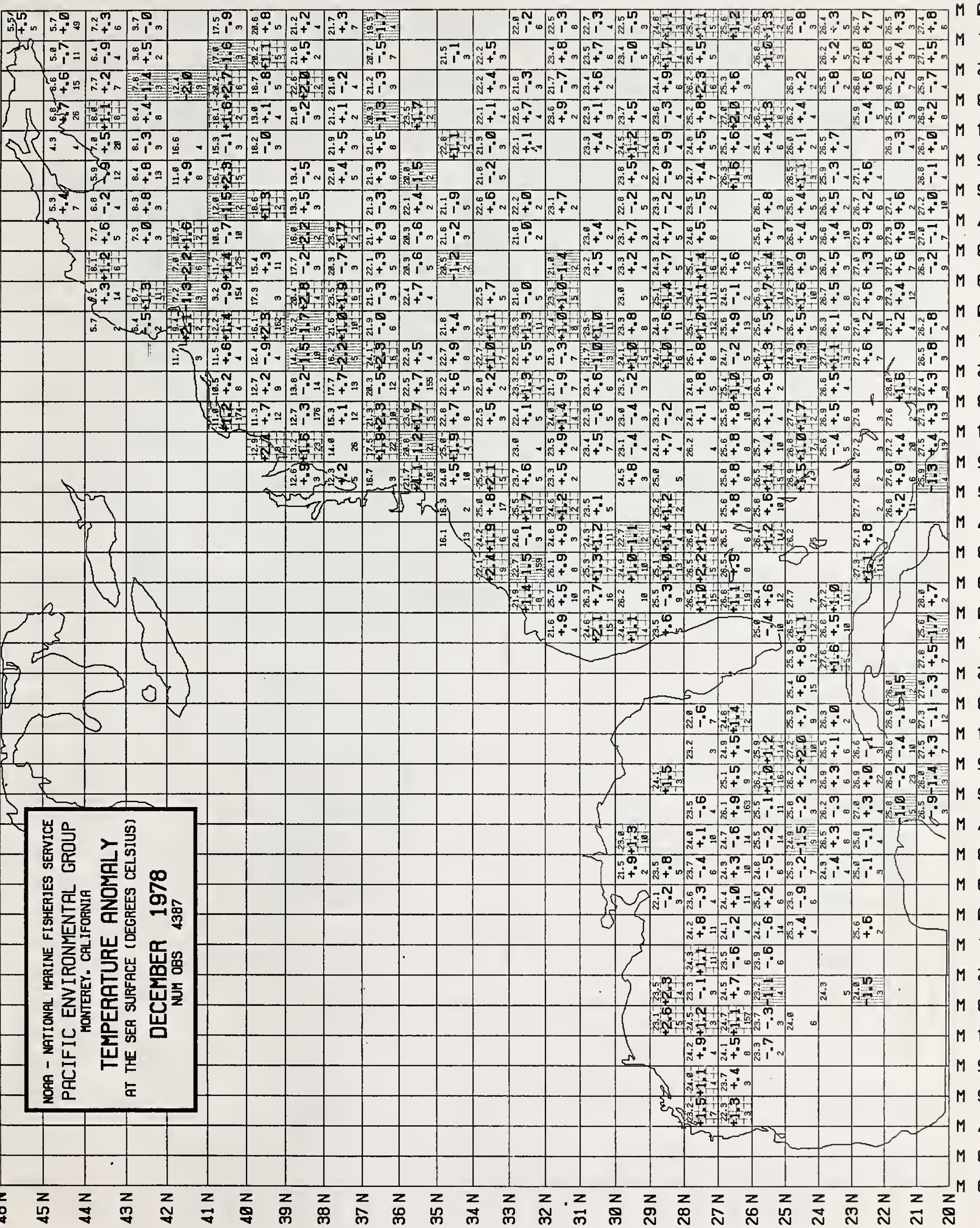
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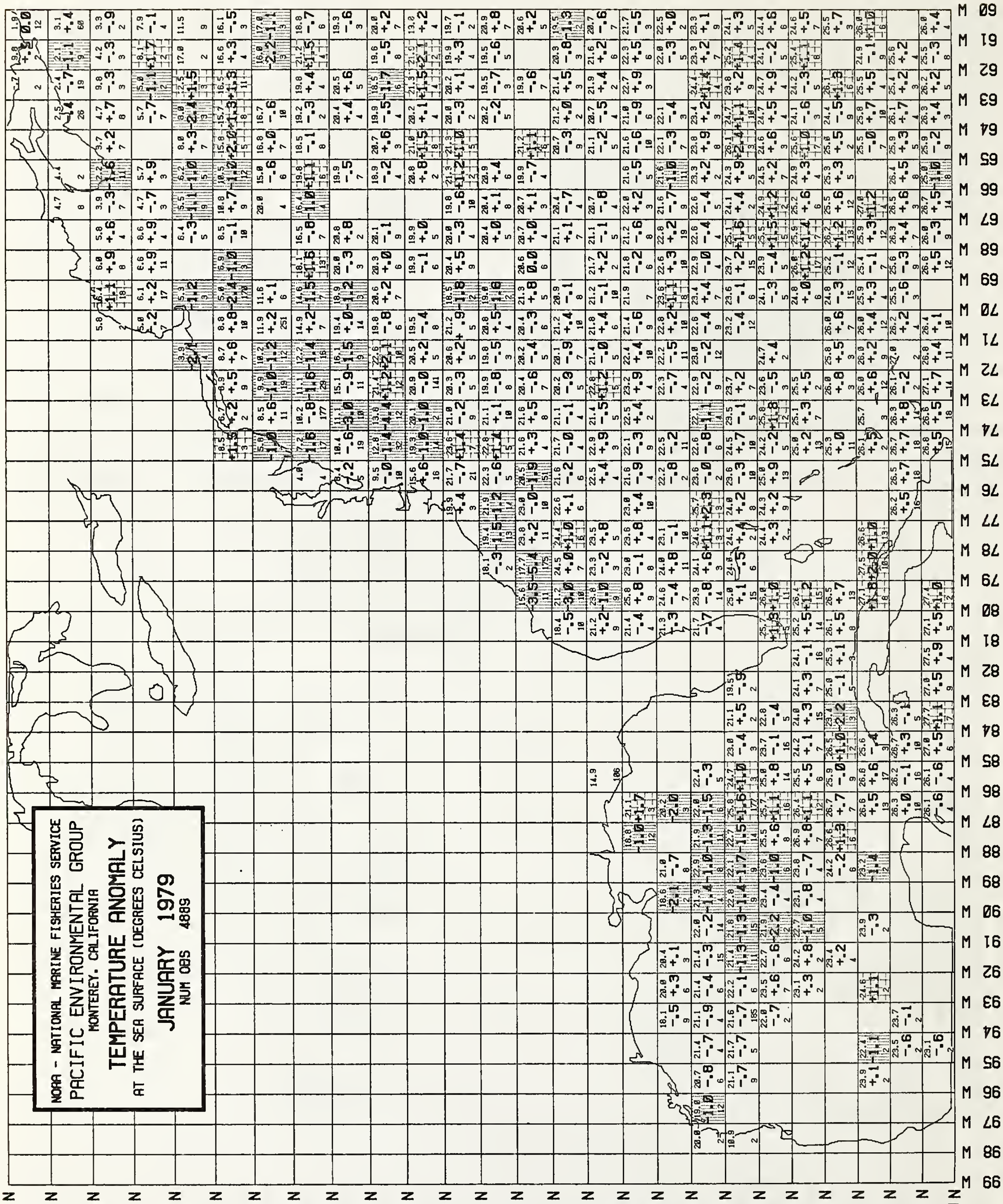
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TEMPERATURE ANOMALY
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JANUARY 1979
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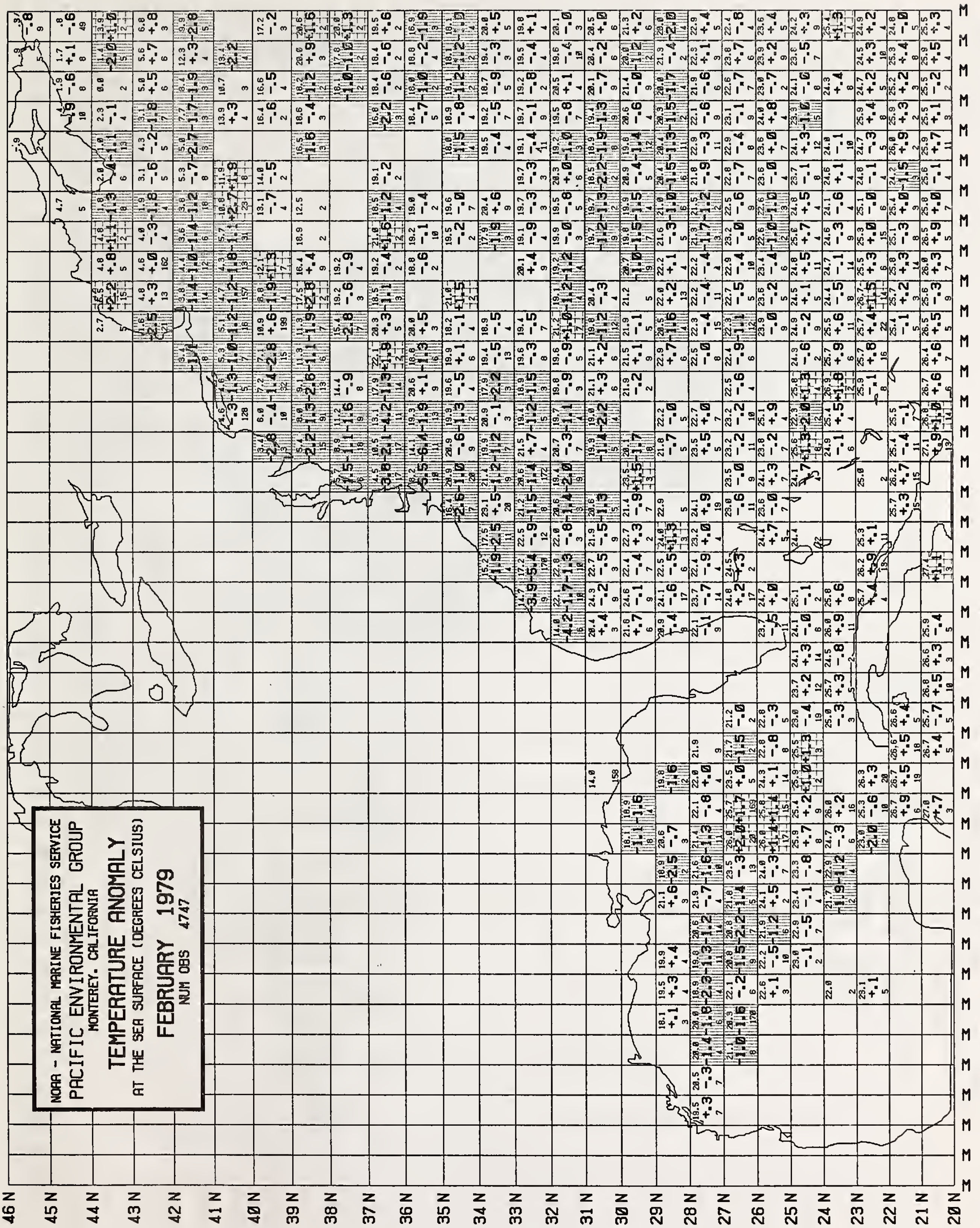
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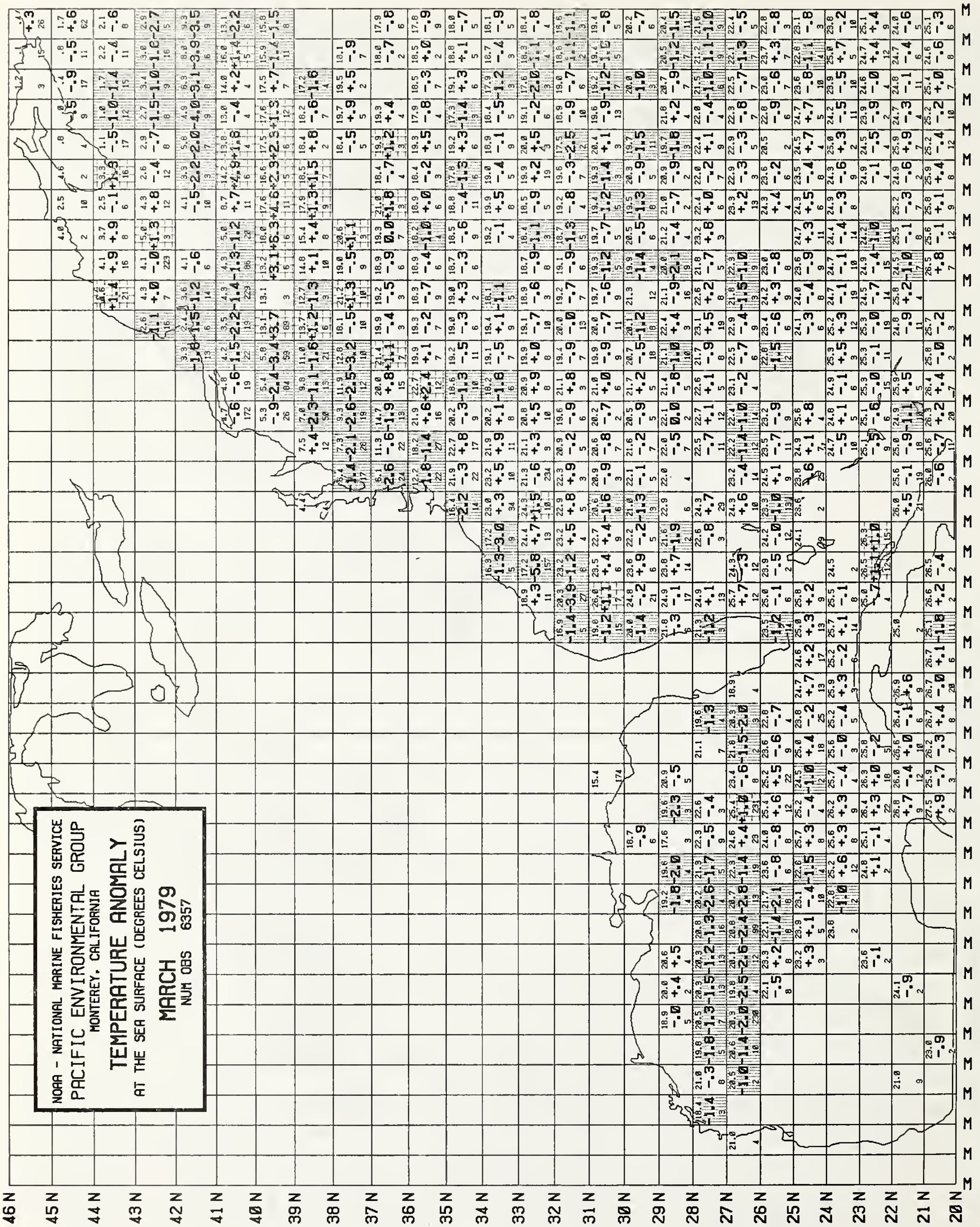

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